Canada

Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

# AN OVERVIEW OF ACHIEVEMENTS IN BIOENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION

Prepared for:

Bioenergy Development Program
Renewable Energy Branch
Energy, Mines and Resources Canada

(February 1987)

Prepared jointly by:

Passmore Associates International
209 - 135 York Street
Ottawa, Ont. K1N 5T4

Ensyn Engineering Inc.
275 MacLaren Street
Ottawa, Ont. K2P 0L9

## FOREWORD

As part of an overall strategy to promote new innovations in the field of renewable energy, Energy, Mines and Resources is offering financial assistance for selected research, development and demonstration (R,D&D) projects in bioenergy. The Bioenergy Development Program is encouraging Canadian industry to expand and develop even more advanced bioenergy technologies which will ultimately allow consumers a greater choice of energy products and services.

This document provides an overview of Canadian accomplishments in the field, assessing both the status and potential of the various technologies. Each chapter concludes with a list of federal project references. These lists are not intended to be comprehensive. In many cases, the information contained in the original project reports may be updated by referring to the proceedings of the Fourth and Fifth Annual Canadian Bioenergy R&D Seminars, edited by S. Hasnain, Elsevier Applied Science Publishers, 1983-84.

For more information on bioenergy projects and programs, contact:

Bioenergy Development Program
Renewable Energy Branch
Energy Policy, Programs and Conservation
Energy, Mines and Resources Canada
Ottawa, Ontario K1A 0E4

(613) 995-9447

TABLE OF CONTENTS


| | | PAGE |
|---|---|---|
| Foreword | | ii |
| Executive Summary | | ix |
| Resumé | | xiii |
| CHAPTER 1 | WHY BIOENERGY? | 1 |
| | 1.1 INTRODUCTION | 1 |
| | 1.2 BIOENERGY DEVELOPMENT IN CANADA | 2 |
| | 1.3 CANADIAN BIOENERGY PROGRAMS | 3 |
| | 1.3.1 Incentive Programs | 3 |
| | (a) Forest Industry Renewable Energy (FIRE) Program | 3 |
| | (b) Canada Oil Substitution Program (COSP) | 4 |
| | (c) Alternate Energy Development Program (AEDP) | 4 |
| | 1.3.2 Research, Development and Demonstration Programs | 4 |
| | (a) Energy from the Forest (ENFOR) Program | 4 |
| | (b) Conservation and Renewable Energy Demonstration (CREDA) Program | 5 |
| | 1.4 THE BIOENERGY DEVELOPMENT PROGRAM | 5 |
| | 1.5 THE FUTURE OF BIOENERGY PROGRAMS IN CANADA | 6 |
| CHAPTER 2 | CANADA'S BIOMASS RESOURCE | 7 |
| | 2.1 INTRODUCTION | 7 |
| | 2.2 THE FOREST-BASED RESOURCE | 7 |
| | 2.2.1 National Forest Biomass Inventory | 8 |
| | 2.2.2 Biomass Production | 9 |
| | 2.3 AGRICULTURAL BIOMASS | 9 |
| | 2.4 MUNICIPAL SOLID WASTE | 10 |
| | 2.5 AQUATIC BIOMASS | 11 |
| | 2.6 PEAT | 12 |
| | 2.7 FEDERAL PROJECT REFERENCES | 12 |

CHAPTER 3 MATERIALS PREPARATION AND HANDLING ..... 13

3.1 INTRODUCTION ..... 13

3.2 BASIC PROPERTIES ..... 13

3.3 MEASUREMENT ..... 15

3.4 UPGRADING ..... 17

3.4.1 Drying ..... 17
3.4.2 Comminution ..... 19
3.4.3 Classification ..... 22
3.4.4 Compaction ..... 23

3.5 MATERIAL TRANSFER ..... 23

3.6 STORAGE ..... 25

3.7 DENSIFICATION ..... 27

3.8 SUMMARY ..... 28

3.9 FEDERAL PROJECT REFERENCES ..... 29

CHAPTER 4 DIRECT COMBUSTION ..... 33

4.1 INTRODUCTION ..... 33

4.2 LARGE-SCALE COMBUSTION ..... 34

4.2.1 Lime Kiln Firing ..... 35

(a) In-situ Combustion of Hog Fuel ..... 35
(b) Suspension-Firing of Pulverized Biofuels ..... 35

4.2.2 Over-Firing of Hog Fuel Boilers ..... 36

4.2.3 Boiler Test Program ..... 36

4.3 MEDIUM-SCALE COMBUSTION ..... 36

4.3.1 Combustors ..... 37

(a) Suspension Burners ..... 37
(b) Single-Chamber Combustors ..... 38
(c) Multiple-Chamber Combustors ..... 38
(d) Fluidized-Bed Combustors ..... 38

4.3.2 Package Boilers ..... 39

CHAPTER 4 DIRECT COMBUSTION (continued)

4.3.3 Technology Development ..... 39

4.3.4 Demonstration Projects ..... 40

(a) Hospitals ..... 40
(b) Greenhouses ..... 41
(c) Educational Institutions ..... 41
(d) Commercial/Industrial Applications ..... 41

4.4 SMALL-SCALE COMBUSTION ..... 41

4.5 SUMMARY ..... 43

4.6 FEDERAL PROJECT REFERENCES ..... 44

CHAPTER 5 CONVERSION TO LIQUID FUELS ..... 45

5.1 INTRODUCTION ..... 45

5.2 DIRECT CONVERSION ..... 45

5.2.1 Pyrolytic Liquefaction ..... 46

(a) Traditional Slow Pyrolysis ..... 46
(b) Vacuum Pyrolysis ..... 47
(c) Fast Pyrolysis ..... 48

5.2.2 Solvolytic Liquefaction ..... 49

(a) Supercritical Fluid Extraction ..... 49
(b) Hydroliquefaction ..... 50
(c) Organosolv Liquefaction ..... 50

5.2.3 Proto-Oil Characterization and Upgrading ..... 51

5.3 INDIRECT CONVERSION ..... 52

5.3.1 Thermochemical Conversion (Gasification/Synthesis) ..... 52

5.3.2 Hydrolysis and Fermentation ..... 53

(a) Pretreatment and Fractionation ..... 54
(b) Enzyme Production and Hydrolysis ..... 56
(c) Fermentation ..... 56

5.4 EXTRACTION ..... 58

CHAPTER 5 CONVERSION TO LIQUID FUELS (continued)

5.5 SUMMARY ..... 59

5.6 FEDERAL PROJECT REFERENCES ..... 59

CHAPTER 6 CONVERSION TO GASEOUS FUELS ..... 63

6.1 INTRODUCTION ..... 63

6.2 THERMOCHEMICAL GASIFICATION ..... 64

6.2.1 Low-Energy Gaseous Fuels ..... 65

(a) Fixed-Bed Gasifiers ..... 65
(b) Stirred-Bed Gasifiers ..... 70
(c) Fluidized-Bed Gasifiers ..... 71
(d) Entrained-Flow Gasifiers ..... 73

6.2.2 Medium-Energy Gaseous Fuels ..... 74

(a) Oxygen Gasification ..... 74
(b) Steam Gasification ..... 75
(c) Pyrolytic Gasification ..... 76

6.2.3 High-Energy Gaseous Fuels ..... 78

6.3 BIOLOGICAL GASIFICATION ..... 79

6.4 SUMMARY ..... 80

6.5 FEDERAL PROJECT REFERENCES ..... 80

CHAPTER 7 CONVERSION TO CHEMICAL FEEDSTOCKS ..... 83

7.1 INTRODUCTION ..... 83

7.1.1 Biomass Components ..... 83

7.2 TRADITIONAL CHEMICAL DERIVATIVES ..... 84

7.2.1 Chemical Pulping ..... 84

(a) Cellulose Derivatives ..... 84
(b) Lignin Derivatives ..... 85
(c) Hemicellulose Derivatives ..... 86
(d) Extractives ..... 86

7.2.2 Destructive Distillation ..... 87

7.2.3 Extractive Processes ..... 87

CHAPTER 7 CONVERSION TO CHEMICAL FEEDSTOCKS (continued)

7.3 BIOENERGY CHEMICALS ..... 88

7.3.1 Thermochemical Processes ..... 88

(a) Supercritical Fluid Extraction ..... 88
(b) Pyrolysis ..... 89
(c) Catalytic Upgrading ..... 90
(d) Byproduct Utilization ..... 90

7.3.2 Biological Processes ..... 91

(a) Lignin Utilization ..... 91

7.4 SUMMARY ..... 92

7.5 FEDERAL PROJECT REFERENCES ..... 92

CHAPTER 8 ENVIRONMENTAL CONSIDERATIONS ..... 95

8.1 INTRODUCTION ..... 95

8.2 ORGANIC MATERIAL REMOVAL ..... 96

8.2.1 Agriculture ..... 96
8.2.2 Forestry ..... 96

8.3 BIOMASS STORAGE AND HANDLING ..... 97

8.4 COMBUSTION ..... 98

8.4.1 National Incinerator Testing and Evaluation Program ..... 99

8.5 THERMOCHEMICAL CONVERSION ..... 99

8.5.1 Noncondensible Gases ..... 99
8.5.2 Condensible Fractions ..... 100

8.6 BIOLOGICAL CONVERSION ..... 100

8.7 SUMMARY ..... 101

8.8 FEDERAL PROJECT REFERENCES ..... 101

INDEX BY PROJECT CONTRACTOR ..... 103

## EXECUTIVE SUMMARY

INCREASINGLY, countries around the world are looking to biomass as an alternative energy source. In Canada, traditional biomass conversion methods are being re-examined and new processes developed. The Bioenergy Development Program is playing a key role in the emergence of bioenergy technologies by assisting Canadian industries to develop new and better systems and equipment.

There are many reasons to develop bioenergy technologies in Canada. Along with other alternative energy sources, bioenergy encourages self-sufficiency and helps protect Canadians from potential oil supply disruptions and price fluctuations. In addition, bioenergy technologies generate local employment, stimulate regional economic development, present important export opportunities in developing countries, and offer environmental benefits.

### Canada's biomass resource

Canada is fortunate in having a varied, abundant biomass resource base on which to build a future in bioenergy technologies. While forests are our greatest source of biomass, other important sources include agricultural residues, municipal and industrial process wastes, peat and aquatic biomass. In recent years, the federal government has compiled comprehensive national inventories of forest biomass, agricultural residues and peat reserves.

The Bioenergy Development Program has identified six priority areas within their research, development and demonstration (R,D&D) program: materials preparation and handling, direct combustion, conversion to liquid fuels, conversion to gaseous fuels, conversion to chemical feedstocks, and environmental considerations.

### Preparation & handling

The efficient handling and reliable feeding of biomass is crucial to any bioenergy process. As a result of federal R,D&D efforts, the fundamental thermodynamic and physical properties of biofuels have been investigated, yielding basic engineering data for the design of preparation and handling systems.

This information has led to the rapid refinement of several techniques. For example, a moisture metering device developed by Forintek Canada Corp. is undergoing field trials to allow

better process control for wood-fired boilers. Similarly, a new bin and silo design developed by B.C. Research provides for efficient storing and transfer of biomass, eliminating flow stoppages. B.C. Research has also developed a promising pneumatic hog fuel conveyor that requires less air and less power than conventional systems.

Feedstock upgrading is another priority area. Projects in drying, comminution (particle size reduction), densification, compaction and classification are improving the quality and uniformity of biomass feedstocks. General Comminution Inc. of Don Mills, Ontario, is currently optimizing the operation of the Szego mill, a ring-roller used to fine-grind wood and bark residues. Another promising innovation is the roll-splitter, used to crush roundwood bolts. As well, Logging Development Corp. of Montreal, Quebec, is designing a central full tree processing complex to maximize use of the forest resource at logging and milling operations.

Direct combustion

Direct combustion is the oldest method of converting raw biomass materials to energy. R,D&D efforts in this area include the development and implementation of a test program to improve the cost-performance of industrial wood boilers. In the past, wood boilers functioned more as incinerators than as energy producers and required substantial amounts of fuel oil to supplement combustion. A number of tested units have not only reported fuel oil savings, some in the $1 million range annually, but have also reduced emissions. In the area of large-scale combustion, the firing of lime kilns using wet screened hog fuel is receiving considerable attention. In medium-scale combustion, many successful demonstrations of commercial prototype systems have been installed in hospitals, greenhouses, educational institutions, and commercial/industrial facilities.

In the residential sector, R,D&D activities have centered on the development of safety, efficiency and emission standards for conventional roundwood burning appliances. As well, the development of completely automatic central, wood-chip furnaces is receiving considerable attention.

Liquid fuels

Research on the direct liquefaction of biomass for the production of liquid fuels and chemicals is a high priority area. Pyrolysis systems are showing particular promise; researchers at the University of Sherbrooke and the University of Waterloo are making important advances in fluidized-bed technology and vacuum pyrolysis. Hydrolytic and organosolv liquefaction processes are being researched at the University of Toronto and the University of Sherbrooke.

In biological conversion, the emphasis is on the enzymatic hydrolysis of cellulose. An Ottawa-based company, Iotech, has already constructed a one-tonne-per-day pilot plant which

converts steam exploded wood to ethanol. Mohawk Oil Company, Canada's only distributor of gasohol, has announced plans for a nine million litre per day expansion of its grain alcohol plant in Minnedosa, Manitoba, based on the Iotech process.

Gaseous fuels

In the area of fluidized-bed oxygen gasification, Canada is at the forefront of world expertise. The medium-energy gas which is generated in this process can be used in the production of chemicals or fuels such as methanol. The work of Inco Metals Co. and Omnifuel Gasification Systems has been critical to the development and commercialization of the oxygen gasification process.

Work is well under way on the operational phase of the world's largest capacity fluidized-bed gasifier (BIOSYN) in St-Juste-de-Bretenières, Quebec. Already, this installation has been used to demonstrate the production of electricity in engine generators using low-energy gas. BIODEV, a sister company to BIOSYN, is installing a similar unit in French Guyana on behalf of Electricite de France.

The production of methane fuel by the anaerobic digestion of biomass is another promising area. A stationary down-flow fixed-film reactor that can operate on animal manure, food processing residues and agricultural wastes is currently being tested in scale-up demonstrations at the National Research Council.

Chemical feedstocks

A variety of important chemical products can be derived from biomass, including plastics, waxes, dyes, scenting agents and emulsifiers. The production of these valuable chemical products can improve the economic viability of many bioenergy processes.

Work in this area is varied: at the University of Western Ontario, a novel ultrapyrolysis process is being developed for the production of ethylene; Prince Albert Pulp has investigated the use of tall oil in diesel engines; and Forintek has evaluated the use of byproduct lignin in adhesives for wood composite products. Still other research groups are working on the catalytic upgrading of the liquid and gaseous products of thermochemical conversion processes.

Environment

Environmental concerns over the large-scale use of biomass for energy centre on the combustion of municipal and forest industry waste streams. In light of the potential for toxic emissions, the Federal Government has established the National Incinerator Testing and Evaluation Program to measure emissions from a variety of energy-from-waste combustion facilities. In addition, a sophisticated computer program, FORCYTE, has been developed to assess the impact of various management systems on forest ecosystems.

RÉSUMÉ

Un peu partout dans le monde, on considère de plus en plus la biomasse comme une source d'énergie de remplacement. Au Canada, on réexamine actuellement les méthodes traditionnelles de conversion de la biomasse et on met au point de nouveaux procédés. Le Programme de développement de la bioénergie joue un rôle clé dans l'émergence des technologies de bioénergie en aidant les industries canadiennes à mettre au point des systèmes et du matériel nouveaux et améliorés.

Il y a plusiers raisons de développer les technologies de bioénergie au Canada. Tout comme les autres sources d'énergie de remplacement, la bioénergie favorise l'autonomie et aide à protéger les Canadiens contre les pénuries éventuelles de pétrole et la fluctuation des prix. En outre, les technologies de bioénergie créent des emplois sur place, stimulent le développement économique régional et offrent d'importantes occasions d'exportations pour les pays en voie de développement, ainsi que des avantages environnementaux.

RESSOURCES EN BIOMASSE AU CANADA

Le Canada a la chance de posséder des ressources biomassiques abondantes et variées qui lui permettront de mettre sur pied une industrie canadienne axée sur des technologies de bioénergie. Bien que nos forêts soient la principale source de biomasse, il en est d'autres qui sont importantes, comme les résidus agricoles, les déchets municipaux et industriels, la tourbe et la biomasse aquatique. Ces dernières années, le gouvernement fédéral a dressé des inventaires exhaustifs de la biomasse forestière, des résidus agricoles et des réserves de tourbe au Canada.

Le Programme de développement de la bioénergie a cerné six domaines prioritaires dans le cadre des activités de recherche, de développement et de démonstration (R, D et D): préparation et manutention des matériaux, combustion directe, conversion en combustibles gazeux, conversion en matières de base pour l'industrie chimique et considérations environnementales.

## PRÉPARATION ET MANUTENTION

Quel que soit le procédé tioénergétique employé, il est crucial que la manutention soit efficace et que l'approvisionnement soit fiable. Grâce aux efforts de R, D et D du gouvernement fédéral, les propriétés thermodynamiques et physiques fondamentales des biocombustibles ont été étudiées, ce qui a fourni les données techniques de base nécessaires à la conception des systèmes de préparation et de manutention.

Cette information s'est traduite par le perfectionnement rapide de plusieurs techniques. Par exemple, un humidimètre mis au point par la Forintek Canada Corp., qui offrira une meilleure régulation des chaudières chauffées au bois, fait actuellement l'objet d'essais in situ. De même, des réservoirs et des silos de conception nouvelle, mis au point par la B.C. Research, permettent d'entreposer et de transporter la biomasse, en éliminant les interruptions d'alimentation. La B.C. Research a également mis au point pour les déchets de bois un convoyeur pneumatique qui nécessite moins d'air et moins d'électricité que les systèmes traditionnels.

L'amélioration des matières de base constitue un autre domaine prioritaire. Des projets portant sur le séchage, la fragmentation (réduction de la taille des particules), la densification, le compactage et la classification permettent d'améliorer la qualité et l'uniformité de la biomasse utilisée comme matière de base. La General Comminution Inc., située à Don Mills (Ontario), cherche actuellement à optimaliser le fonctionnement du moulin Szego, un moulin à cylindres annulaires, utilisé pour réduire les résidus de bois et d'écorce en fines particules. Le défibreur à rouleau utilisé pour écraser les billes de bois est une autre innovation prometteuse. En outre, la Corporation de recherche Logging Development de Montréal (Québec) travaille actuellement à la conception d'un complexe central pour le traitement des arbres entiers qui permettra de maximiser l'utilisation des ressources forestières au cours des opérations d'abattage et de broyage.

## COMBUSTION DIRECTE

La combustion directe est la méthode la plus an- cienne qui soit utilisée pour convertir la biomasse brute en énergie. Les efforts de R, D et D dans ce domaine ont

consisté à élaborer et à appliquer un programme d'essai pour améliorer la rentabilité des chaudières industrielles chauffées au bois. Aupa- ravant, ces chaudières servaient davantage d'inci- nérateurs que de source d'énergie et nécessitaient des quantités importantes de mazout pour aider à la combustion. Avec certains des nouveaux brûleurs qui ont été testés, on a non seulement réalisé des éco- nomies de mazout, de l'ordre d'un million de dollars par année, mais on a aussi réduit les émissions.

En ce qui concerne la combustion dans de grandes installations, l'utilisation de déchets de bois criblés à l'état humide pour alimenter les fours à chaux suscite beaucoup d'intérêt. Pour ce qui est de la combustion dans des installations de taille moyenne, de nombreux prototypes commerciaux ont été installés avec succès dans des hôpitaux, des serres, des établissements d'enseignement et des installations commerciales ou industrielles.

Dans le secteur résidentiel, les activités de R, D et D ont été concentrées sur l'élaboration de normes relatives à la sécurité, à l'efficacité et aux émissions des appareils alimentés avec du bois de chauffage. En outre, la mise au point de systèmes de chauffage central, entièrement automatique et alimentés avec des copeaux de bois reçoit une attention considérable.

## CARBURANTS LIQUIDES

La recherche sur la liquéfaction directe de la biomasse en vue de la production de produits chimiques et de carburants liquides constitue un secteur prioritaire. Par ailleurs, les systèmes de pyrolyse sont particulièrement prometteur. Les chercheurs de l'Université de Sherbrooke et de l'Université de Waterloo font actuellement des progrès importants dans le domaine de la technologie des lits fluidisés et de la pyrolyse sous vide. Les procédés de liquéfaction par hydrolyse et avec des solvants organiques font l'objet de recherches à l'Université de Toronto et à l'Université de Sherbrooke.

Dans le domaine de la conversion biologique, on s'intéresse surtout à l'hydrolyse enzymatique de la cellulose. La Iotech, une entreprise établie à Ottawa, a déjà construit une usine pilote d'une

capacité de 1 tonne par jour, qui produit de l'éthanol par traitement à la vapeur du bois. Par ailleurs, la Mohawk Oil Company, seul distributeur de carburol au Canada, a annoncé son intention d'agrandir son usine d'éthanol située a Minnedosa (Manitoba) pour lui donner une capacité additionnelle de 9 millions de litres par jour, en se basant sur le procédé de la société Iotech.

## COMBUSTIBLES GAZEUX

Le Canada est à la fine pointe de la technologie dans le domaine de la gazéification en présence d'oxygène sur lit fluidisé. Le gaz moyennement riche obtenu avec ce procédé peut être utilisé dans la production de produits chimiques ou de carburant comme le méthanol. Les travaux de l'Inco Metals Co., et d'Omnifuel Gasification Systems ont été des facteurs déterminants dans l'élaboration et la commercialisation du procédé de gazéification en présence d'oxygène.

La phase opérationnelle des travaux portant sur le gazéificateur à lit fluidisé BIOSYN, dont la capacité est la plus élevée au monde, est assez avancée. Déjà, cette installation, située à St-Juste-de-Bretenières (Québec), a été utilisée comme installation de démonstration pour produire de l'électricité grâce à des génératrices mues par des moteurs alimentés avec un gaz pauvre. La société BIODEV, société soeur de BIOSYN, installe actuellement une unité analogue en Guyanne française, pour le compte d'Électricité de France.

La production de méthane par digestion anaérobie est un autre domaine prometteur. Un réacteur stationnaire à débit descendant et à pellicule fixe pouvant être alimenté avec du fumier, des résidus du traitement des aliments et des déchets agricoles fait actuellement l'objet d'essais à échelle plus grande, au Conseil national de recherches.

## PRODUITS CHIMIQUES

Divers produits chimiques importants, comme les plastiques, les cires, les colorants, les agents odorants et les émulsifiants, peuvent être préparés à partir de la biomasse. La préparation de ces produits de valeur peut améliorer la viabilité économique de nombreux procédés bioénergétiques.

Les travaux réalisés dans ce domaine sont variés: à l'Université Western Ontario, un nouveau procédé visant à produire de l'éthylène par ultrapyrolyse est en cours d'élaboration, la Prince Albert Pulp étudie la possibilité d'utiliser le tall oil dans les moteurs diesel, et la Forintek a évalué l'emploi de déchets de lignine dans les adhésifs utilisés dans la fabrication de produits composites du bois. De plus, d'autres groupes de recherche travaillent à l'enrichissement catalytique des produits liquides et gazeux des procédés de conversion thermochimique.

## L'ENVIRONNEMENT

L'utilisation à grande échelle de la biomasse comme source d'énergie suscite des inquiétudes, particulièrement en ce qui concerne les effets de la combustion des déchets des municipalités et de l'industrie forestière sur l'environnement. Étant donné le risque d'émissions toxiques, le gouvernement fédéral a mis en oeuvre le Programme national d'essai et d'évaluation des incinérateurs afin de mesurer les émissions des diverses installations de production d'énergie par combustion de déchets. De plus, un logiciel perfectionné, FORCYTE, a été élaboré pour évaluer l'effet de divers systèmes de gestion sur les écosystèmes forestiers.

# CHAPTER 1

# WHY BIOENERGY?

# CHAPTER 1

# WHY BIOENERGY?

## 1.1 INTRODUCTION

IN ANY CONSIDERATION of bioenergy, the overriding impression is that of diversity -- both diversity of biomass feedstocks and diversity of available technologies with which to convert those feedstocks to energy.

Canada's biomass resource has many sources -- forests, agriculture, aquatic environments, and industrialized society itself. As well, the form and characteristics of biomass feedstocks vary from solid chunks such as firewood and peat, to particulates such as sawdust and apple pomice, to high organic content liquid streams such as pulping liquors, whey and sewage.

These feedstocks can be converted into energy by a host of technologies, some traditional, some innovative. These include the direct combustion of biomass and the conversion of organic feedstocks into a variety of solid, liquid or gaseous prepared fuels. The abundance of potential feedstocks, products, and processes creates an immense matrix of technologies that all come under the umbrella of bioenergy.

Biomass currently supplies more than 6.8 percent of Canada's overall primary energy demand. In the industrial sector, its contribution is 17 percent; in the residential sector, 14 percent. By far, the largest user of biomass for energy is the forest products industry. By burning spent pulping liquor and wood waste, pulp mills and logging operations supply more than 40 percent of their own energy requirements. Even so, unused forest biomass associated with conventional logging and milling activities in Canada each year contains the energy equivalent of some 120 million barrels of oil.

Residential wood heating, excluding open fireplaces, is another significant user of bioenergy, with over 2 million or 25 percent of Canadian homes burning wood as a primary (greater than 50 percent) or secondary (10 to 50 percent) heating source.

## 1.2 BIOENERGY DEVELOPMENT IN CANADA

In the late 1970s, energy forecasts indicated that the price of oil might rise to $60 per barrel by 1990 and that, as a net importer of approximately 300,000 barrels of oil per day, Canada could find itself in a vulnerable position. At that time, bioenergy supplied about three percent of the country's primary energy demand, but the potential for additional, economic bioenergy applications and increased energy contribution was evident.

While $60-a-barrel oil has not yet materialized and Canada is no longer a net importer of oil, prices and markets continue to be unstable and energy security is still an issue. Moreover, with Canada's overwhelming abundance of renewable, indigenous biomass materials, the potential for additional job creation, further regional development, and export opportunities is considerable. Bioenergy technologies also offer environmental benefits, such as reduced dumping at landfill disposal sites.

There are, however, barriers that impede the growth of bioenergy as an energy alternative. These include:

* the high risk and cost of introducing new technologies,
* consumer acceptance,
* lack of public awareness,
* a weak supply structure,
* lack of technical expertise,
* lack of precise knowledge of bioenergy supply, availability and costs.

Compared to oil and natural gas, many biomass fuels are difficult to handle, prepare and use. Problems such as high moisture content, low energy density, irregular sizing, and presence of impurities, as well as a lack of uniform, standard engineering properties reduce the attractiveness and efficiency of using biomass fuels. In addition, great tracts of Canada's wealthiest biomass reserves are located far from energy-using urban centres. Bioenergy processes have also come under close scrutiny for potential pollution hazards.

To encourage Canadian companies and industries to convert existing petroleum-based systems to biomass fuels, the economics and dependability of bioenergy must be evident. Federal projects are providing information on heating value, friction coefficients, shear strength, pile forces, ash content, and elemental analysis. They are also looking at the measurement of biomass feedstocks (green weight versus dry matter content) and the transportation of raw biomass materials. As a result, technical expertise is being honed, new, more efficient technologies developed, and existing technologies fine-tuned.

Bioenergy has already established its place as part of Canada's energy strategy. With Federal Government support, many of the most promising bioenergy technologies and systems are being researched, developed and demonstrated. Some are being implemented for immediate use; others are being developed to ensure their readiness should future economic or environmental circumstances permit their implementation.

## 1.3 CANADIAN BIOENERGY PROGRAMS

Canadian government involvement in the development of bioenergy began in earnest in 1978. In that year, the government introduced several program initiatives in conservation and renewable energy aimed at the industrial, commercial and residential sectors. These programs were designed to address both technical and socio-economic barriers: the high capital cost of developing and of purchasing bioenergy conversion equipment, the underdeveloped supply infrastructure, the lack of technical expertise, and the general lack of awareness of bioenergy's potential contribution.

Some of these programs offered direct incentives to the bioenergy user; others supported research, development and demonstration (R,D,&D) of bioenergy technologies and applications. The overall objective was, and remains, to increase the total bioenergy contribution.

### 1.3.1 Incentive Programs

#### 1.3.1 (a) Forest Industry Renewable Energy (FIRE) Program

Of the programs initiated in the first round of announcements, the FIRE Program was the most ambitious. With a budget of $96 million, its purpose was to promote energy security and energy self-sufficiency by substituting biomass fuels for fossil fuels in the forest products industry. When the National Energy Program was announced in 1980, FIRE was expanded to include nonforest industrial, commercial, and institutional organizations as well as other forms of biomass such as municipal and agricultural wastes and peat. Only commercially available, proven technologies were eligible.

The FIRE Program officially ended March 31, 1986, and is now in a two-year wind-down period. The program has been responsible for 180 projects, mostly in the forest products industries. When completed, these projects will displace approximately 9.3 million barrels of oil equivalent (BOE) per year.

1.3.1 (b) Canada Oil Substitution Program (COSP)

Established in 1980 as part of the National Energy Program, COSP was aimed at the residential sector and provided a one-time, taxable grant of up to $800 for homeowners to convert from oil to natural gas, electricity, solar or wood. The program was ended ahead of schedule in 1985 as part of a general government effort to control expenditures.

Under COSP, approximately 225,000 grants (23 percent of all program conversions) totaling $230 million were issued to homeowners to convert from oil to wood heating.

1.3.1 (c) Alternate Energy Development Program (AEDP)

The AEDP was initiated in 1984 as a special bioenergy program for Prince Edward Island. A small, largely rural population and a paucity of fossil and hydro reserves have pushed energy costs on the Island considerably higher than in other areas of Canada. At the same time, the Island has a large forest biomass resource. Under the program, commercial, industrial and institutional facilities are eligible for contributions of up to 62.5 percent of the total cost of installing biomass conversion systems.

Working hand in hand with the AEDP is a massive forest management and improvement program to provide bioenergy users with woodchip fuel. The program, which runs to 1989, is expected to displace some 50,000 BOE per year.

1.3.2 Research, Development and Demonstration Programs

---

1.3.2 (a) Energy from the Forest (ENFOR) Program

Initiated in 1978 and administrated by the Canadian Forestry Service (CFS) of Environment Canada, ENFOR was Canada's first major forest research and development program. The major objective of the five-year, $30 million plan was to promote the development of technology aimed at substituting forest biomass for nonrenewable fuels and chemicals. The program consisted of two elements: biomass production (resource assessment and the supply of raw materials) and biomass conversion (the transformation of raw materials into energy, prepared fuels, and energy-intensive chemicals).

In 1983, responsibility for biomass conversion was transferred from the ENFOR Program to EMR's Renewable Energy Branch to permit better integration of biomass activities with other EMR initiatives. Restructured under a new title, the Bioenergy Development Program, the program is no longer exclusive to forest biomass. Rather, it is now concerned with the R,D&D of process prepared fuels and chemicals from all

biomass sources. The Canadian Forestry Service is still responsible for the biomass production component of ENFOR.

When the National Energy Program was announced in 1980, energy R&D funding was greatly expanded and the number of government departments involved in bioenergy swelled. In addition to the CFS's activities, Energy, Mines and Resources (EMR), Agriculture Canada, Environment Canada, and the National Research Council (NRC) all managed bioenergy R&D programs. Most of these programs, coordinated by the Bioenergy Program Office of the NRC, have since been integrated into EMR's Bioenergy Development Program.

### 1.3.2 (b) Conservation and Renewable Energy Demonstration (CREDA) Program

In parallel with the research and demonstration efforts described above, the Federal Government also initiated the CREDA demonstration program in 1978. Managed by EMR, the objective of this program was to demonstrate promising new technologies and applications that used renewable energy sources, conserved energy, or improved energy efficiency. A bilateral program, CREDA involved cost-shared agreements with the provinces. Now in the wind-down stage, CREDA's demonstration activities were to be assumed by the short-lived ENERDEMO Canada program. Responsibility for demonstrations has since been assigned to EMR's Bioenergy Development Program.

Over one hundred bioenergy demonstration projects have been carried out under these programs at a cost to the government of $12 million. Examples include cogeneration at energy-from-waste facilities, wood-fueled district heating, wood-chip furnaces and boilers, anaerobic digestion of hog manure, medium-scale and whole-tree wood chippers, and large-scale, fully automated wood heating systems.

## 1.4 THE BIOENERGY DEVELOPMENT PROGRAM

The Bioenergy Development Program (BDP) is comprised of R&D as well as demonstration activities and is managed by the Bioenergy Division of EMR. The program operates exclusively on a contracting out basis to industry, research organizations and universities. Technology and information transfer activities are also an integral part of the program.

The program's near-term objective is to develop and refine bioenergy technologies and equipment, particularly in forest and agricultural biomass, as well as municipal solid waste and peat. The principal long-term objective is to establish in Canada the technology and industrial expertise necessary for the efficient future production of fuels and industrial chemicals from biomass.

As more technical and economic information becomes available, a more directed program approach for certain technologies will be undertaken. In general, however, the program will remain reactive to industry needs. In this way, the program can respond quickly to industry requirements, ensuring that product and technology development is market driven.

Priority areas identified for further R,D&D include the following:

* materials handling and pretreatment (materials metering, size modification, removal of contaminants, moisture reduction and monitoring),

* direct combustion (hog fuel burners, fluidized-bed combustors, suspension burners, single and multiple-chamber combustors, automated control systems, and performance testing and design evaluation of wood stoves),

* thermochemical and biological conversion to prepared fuels and chemicals (the production of solid, liquid and gaseous fuels, as well as industrial chemicals),

* information transfer, including information exchange with other International Energy Agency countries.

## 1.5 THE FUTURE OF BIOENERGY PROGRAMS IN CANADA

According to current estimates, bioenergy now contributes approximately 6.8 percent of Canada's primary energy demand or about 242,000 BOE per day. This contribution is mainly in the residential and industrial sectors of the economy for which bioenergy contributes approximately 14 percent and 17 percent of the secondary energy use respectively.

Under the National Conservation and Alternative Energy Initiative (NCAEI) announced by the Federal Government in 1985, bioenergy will continue to receive significant funding. However, the trend will be away from large incentive programs such as FIRE and toward more selective R,D&D and information transfer. While work on promising longer-term opportunities will continue, the emphasis will be on shorter-term applications.

# CHAPTER 2

# CANADA'S BIOMASS RESOURCE

# CHAPTER 2

# CANADA'S BIOMASS RESOURCE

## 2.1 INTRODUCTION

THE TERM BIOMASS includes materials composed largely of carbon, hydrogen and oxygen that have been produced from the photosynthetic activity of plants. In the context of bioenergy, potential feedstocks are considered to be that portion of available biomass which is not utilized for food or higher value products. These feedstocks have widely differing physical characteristics and are often generated as wastes by industry (primarily the forest products industry), the agrifood sector, and municipalities. Other sources include aquatic biomass and peat.

Biomass is extremely versatile in its variety of end uses. It can be burned, gasified, liquefied, or partially oxidized to synthesis gas. It can also be broken down into different components or chemicals that can be used in many energy and non-energy applications. In addition, biomass can be processed through chemical or biological action into a substitute natural gas (SNG) for use as a chemical or liquid fuel precursor. Biomass-derived materials can also substitute for many refined petroleum products. This versatility means that bioenergy forms can be easily integrated into conventional energy systems without major disruptions to current energy use patterns.

In the long term, bioenergy is expected to make an increasing and sustainable contribution to Canada's energy supply. Its role in our energy future depends largely on the future supply price of biomass and the cost of conversion technologies compared to other alternative and conventional energy sources.

## 2.2 THE FOREST-BASED RESOURCE

There is no doubt that this country's forest resource offers the greatest potential for bioenergy in Canada. Forest biomass sources are broadly divided into the following categories:

* Mill residues are the waste byproducts associated with the processing of forest materials. Bark, sawdust, solid trim, shavings, veneer clippings, sanderdust, clarifier sludge, pulping liquors and clarifier effluents represent some of the lowest cost biomass. With prices ranging down from $15 per dry tonne, these materials represent over 14 percent of available forest biomass. Much of this residue is converted to energy on site for use by the forest products industry itself.

* Logging residues are the residual materials left in the forest following harvesting. In conventional forest harvesting techniques, as much as half of the total available biomass is left on the site. These forest residues, which include slash (e.g., tops and branches), small trees, deformed and defective trees, sortyard debris, thinnings, land clearing residues, stumps and roots, increase susceptibility to fires and disease and interfere with reforestation efforts. Representing almost 22 percent of the total available forest biomass, removal of this material results not only in better resource utilization, but also in a tremendous increase in biofuel production. However, logging residues tend to be somewhat difficult and costly to collect, ranging in price from $25 to $90 per dry tonne.

* Salvage includes wood killed by fire, insects, disease, wind and flooding. It represents just under 25 percent of available forest biomass.

* Stand conversion, the use of noncommercial trees and scrub for energy purposes, represents almost 10 percent of available forest biomass.

* Merchantable surplus is that biomass material over and above the industry demand for fibre used in the manufacture of conventional forest products. In Canada, this surplus is close to 30 percent of the total available forest biomass. The cost of biomass from salvage, stand conversion, and merchantable surplus ranges from $30 to $60 per dry tonne.

### 2.2.1 National Forest Biomass Inventory

Although Canada possesses vast quantities of biomass, accurate information on the location, nature, quantity and cost of that biomass is required to ensure its effective and efficient utilization for energy.

To this end, a comprehensive national inventory of forest biomass was published in 1985 [project ref. 2.1]. Canada's first complete forest inventory and first forest biomass inventory, the project was spearheaded by ENFOR in cooperation with the Canadian Forestry Service and provincial forestry agencies.

According to the report, the total Canadian forest biomass resource exceeds 26 billion oven-dry tonnes (ODT). The quantity of forest biomass available for energy purposes, defined as the nonmerchantable portion of merchantable size trees growing on productive, accessible forest land, is 4 billion tonnes, or 16 percent of the total forest biomass. This quantity could supply about 25 percent of Canada's annual energy requirements on a sustained basis.

As much as possible, the inventory used existing forest data. However, new data from areas of forest land not previously inventoried (e.g. northern Quebec, Ontario and Manitoba) and areas previously inventoried but not field sampled (e.g. unproductive forest lands) were also included. The inventory was unique in that it categorized trees into eight biomass units -- foliage, tops, branches, stem wood, stem bark, stump wood, stump bark, and submerchantable or small trees. It also classified the data by physical access to give some indication of the degree of difficulty and cost of harvesting.

### 2.2.2 Biomass Production

The are two basic ways in which Canada's biomass supply can be increased -- better silvicultural practices and increased use of energy plantations.

Ongoing efforts in biomass production include the development of improved harvesting and forest management techniques, the development of equipment for the harvesting of logging residues, and the development of a sophisticated computer program (FORCYTE) used to assess the impact of various forest management systems on the forest ecosystem.

Canada has also established itself as a world leader in the development of fast growing short-rotation hybrid poplars. A number of experiments in planting commercial stands of hybrid poplar are now in progress in eastern Ontario, Quebec and British Columbia. In the long term, the growth rates and yields of hybrid poplars and other species may be further improved through genetic manipulation and tissue culture techniques.

## 2.3 AGRICULTURAL BIOMASS

In 1982, Agriculture Canada commissioned regional studies to determine the energy production potential from the Canadian agriculture and food system. Based on these studies, a national assessment concluded that 6.5 to 7.4 million tonnes at field moisture levels) of the more than 40 million tonnes

of agricultural crop residues produced annually in Canada are potentially available for energy production purposes [project ref. 2.2]. Another study identified five million tonnes as potentially available for ethanol production [project ref. 2.3].

These estimates are substantially lower than those of previous studies. They are based on a diverse group of potentially combustible crop residue sources including straws, stovers, chaff, corn cobs, bean residues, sugar beet tops and tobacco stalks. Other agricultural residues that could be considered for energy purposes include processing residues such as weed seeds, hulls and husks, potato culls, nut shells, apple pomice, sugar beet pulp, whey, and stillage. Sources of animal residues include manure and slaughterhouse waste.

The availability of crop residues for energy purposes is heavily constrained by the competing demands of soil reincorporation and animal feeding and bedding. Residues in excess of these needs are available mostly in central and eastern Canada. Soil reincorporation needs in the Prairies are sufficiently high that little or no straw is available for energy production.

Agricultural residue-based energy production systems can provide important opportunities in the farming sector. Estimates indicate that over 11,000 Canadian farms have residues in sufficient quantities to justify farm or community level energy production systems. Feedstock and capital costs are critical factors affecting the cost of producing energy. Residues such as corn cobs and cereal chaff present unique opportunities since they possess little or no value for alternative uses.

Additional resource opportunities may become available as novel processing techniques and innovative cropping systems increase the yield of agricultural biomass. Also, plantations of multi-purpose crops, such as kochia, milkweed, alfalfa and Jerusalem artichoke, can make better use of marginal lands and saline soils.

## 2.4 MUNICIPAL SOLID WASTE

Municipal solid waste (MSW) is currently attracting much attention as an energy source. MSW can be burned in "energy from waste" plants to provide energy in the form of steam or electricity. At the same time, this practice helps alleviate ground water pollution and reduces the rapidly increasing cost of traditional landfill disposal methods.

MSW includes all wastes normally disposed of at municipal sanitary landfill sites or incinerators. These include wastes

generated by the residential, institutional and commercial sectors, as well as some industrial wastes. Examples of usable MSW materials include paper, cardboard, textiles, leather and putrescible organics, as well as some high moisture content wastes such as potato sludge and apple pomice. Sewage sludge is normally excluded.

In contrast with other biomass forms such as wood residues, MSW is difficult to collect and burn. It is also extremely heterogeneous and relatively low in energy, having only about half the heating value of coal. Due to these difficulties, MSW plants usually sell their energy to a nearby customer, such as a hospital, university complex, or industrial facility with standby steam facilities. Alternatively, the steam produced can be converted to electricity and sold to the utility grid.

Utilization of MSW wastes for energy production depends primarily on the cost of existing landfills and constraints on establishing new landfills, as well as the availability of a potential energy user. Generally, only urban centres with a population greater than 7,000 generate enough waste to support the operation of an MSW plant. Currently, there are three active MSW-burning energy systems in Canada. Located in Charlottetown, Quebec City and Hamilton, they use only five percent of the 4 million oven-dry tonnes of MSW available in Canada each year [project refs. 2.4, 2.5].

## 2.5 AQUATIC BIOMASS

While marine and freshwater vegetation is receiving serious consideration as an energy crop in other countries, its potential in Canada is limited.

Two plant types have been investigated -- millfoil and seaweed. Urasian millfoil is a freshwater weed that routinely contaminates waterways. Thousands of dollars are spent each year clearing boating channels and swimming areas. In a

CBCL Ltd.

National Research Council (NRC) sponsored study, CBCL Ltd. of Ottawa, Ontario, examined more efficient ways to collect the material and also evaluated its energy value [project ref. 2.6]. They found that the plant has a high ash content which decreases it heat value and, hence, its usable energy. They also discovered that it is extremely difficult to dewater.

Loucks Oceanology

In another NRC study, Loucks Oceanology of Halifax, N.S., investigated the potential of seaweed as an energy crop [project ref. 2.7]. Many seaweeds, such as Irish moss, are already commercially harvested for use as gums, latexes and emulsifiers. The manufacture of these materials produces tremendous waste streams which could be treated to yield methane gas. However, Canada's seaweed industry is not large enough to support the sideline production of energy. In

addition, it appears that ocean and lobster fishing have already seriously depleted harvestable sea biomass. Finally, seaweed exhibits a relatively low energy value.

## 2.6 PEAT

Peat is considered a long-term energy option for Canada. While domestic R,D&D is winding down, Canada will continue to collaborate with the International Energy Agency on peat dewatering and mining projects. A comprehensive peat inventory has been established and is on file at Agriculture Canada.

## 2.7 FEDERAL PROJECT REFERENCES


2.1 Bonner, G.M., "Inventory of Forest Biomass in Canada", Petawawa National Forestry Institute, Canadian Forestry Service, 1985.

2.2 Colwell, H.T.M., "The Potential for a Sustained Energy Supply from Combustible Crop Residues in the Canadian Agriculture and Food System -- A National Assessment", prepared for Agriculture Canada, April 1983.

2.3 Hayes, R.D., "Availability of Crop Cellulosics for Ethanol Production", Engineering and Statistical Research Institute, Agriculture Canada, October 1983.

2.4 "Strategy for Bioenergy Infrastructure Development and Market Penetration in Eastern Canada" (for EMR), Cogeneration Associates Ltd., January 1985.

2.5 "Bioenergy Projects: Potential, Classification and Implementation Logistics Study for Western Canada" (for EMR), Canadian Resourcecon Ltd., October 1983.

2.6 "Energy from Aquatic Biomass" (for NRC), CBCL Ltd., Ottawa, Ont., 1981.

2.7 Smith, R., Loucks, R., "Assessment of Seaweed Biomass" (for NRC), Loucks Oceanology, Halifax, N.S., 1980.

# CHAPTER 3

# MATERIALS PREPARATION AND HANDLING

# CHAPTER 3

# MATERIALS PREPARATION AND HANDLING

## 3.1 INTRODUCTION

CONVENTIONAL FUELS such as oil, gas and coal are marketed according to specific standards that guarantee final uniformity in product composition. As a result, the user is not faced with further fuel preparation and can depend upon a proven off-the-shelf handling system developed through years of experience and reliable engineering design.

By contrast, biomass exhibits some of the most undesirable characteristics in a fuel material: low energy density, high moisture content, high impurity levels, and unpredictable physical and chemical behaviour.

Preparation and handling are vital to the successful utilization of biomass, yet early developments in preparation and handling systems were largely trial and error, often depending upon knowledge obtained from fossil fuel processing. Consequently, the performance of many bioenergy systems was less than satisfactory.

In recent years, federal R,D&D efforts have concentrated on the development and testing of equipment specific to the use of biomass for energy. Some projects have focused on moisture content determination, thermal and mechanical drying, and particle size reduction (comminution). Equipment and systems have also been developed to clean and classify biomass feedstocks by particle size. Still other projects have centred on compaction and densification, material transfer, and storage.

## 3.2 BASIC PROPERTIES

The most important properties relating to the preparation, handling and final conversion of biomass materials to energy or prepared fuels are heating value, moisture content, bulk density and contamination.

Higher Heating Value: This is the maximum amount of heat or energy that can be recovered from a material and is determined by completely combusting a sample under controlled

laboratory conditions. Analogous terms include heat of combustion, fuel value and calorific value.

Forintek

Feedstock heating values have been widely studied. A federally sponsored project carried out by Forintek provides an in-depth review of published data on woody materials [project ref. 3.1]. According to the report, the heating value of most Canadian tree species is relatively constant, averaging about 21.2 megajoules per oven-dry kilogram (MJ/kg) for softwoods and 19.3 MJ/kg for hardwoods. Small variations in heating value were noted between different components of a tree, such as stem and branch material.

The higher heating value of other biomass fuels, however, varies widely: bulk municipal solid wastes average 10 to 12 MJ/kg; refuse-derived fuels, 13 to 14 MJ/kg; and agricultural residues such as cereal grain straws or corn stover, 16 to 19 MJ/kg. On the low end of the scale, high ash aquatic biomass has a heating value of as little as 10 to 11 MJ/kg.

The actual energy that can be recovered from any given biomass feedstock in an industrial conversion process is substantially lower than its highest heating value and depends on several factors, principally fuel moisture content and combustor efficiency.

Moisture Content: The moisture content of biomass is defined as the quantity of water in the material expressed as a percentage of the material's wet weight. Biofuels exhibit a wide range of moisture contents: less than 10 percent for cereal grain straw, 20 to 30 percent for municipal solid waste, 50 to 70 percent for forest residues, and over 95 percent for waste streams from food processing industries.

For most thermochemical conversion processes (combustion, gasification, pyrolysis), high moisture content reduces efficiency since the energy consumed in evaporating the excess water is not recovered. Biological conversion processes, on the other hand, normally occur in an aqueous medium and a high feedstock moisture content is beneficial.

Bulk Density: Bulk density refers to the weight of material per unit volume and, for biomass, is commonly expressed on an oven-dry weight basis or an as-is basis with a corresponding indication of moisture content. Similar to biomass moisture contents, biofuel bulk densities show extreme variation, from lows of 150 to 200 kg/cubic metre for cereal grain straws and shavings to highs of 600 to 800 kg/cubic metre for solid wood.

Together, heating value and bulk density give a measure of energy density, i.e. the potential energy available per unit volume of the biofuel. In general, biofuel energy densities are approximately one-tenth that of fossil fuels such as petroleum or high quality coal.

Elemental Composition and Contamination: The composition of the ash-free organic component of biomass is relatively uniform. The major constituents are carbon and oxygen, representing roughly 45 to 53 percent and 40 to 60 percent respectively. The hydrogen content is much less, but significant at about 6 to 6.5 percent. Also, a small proportion of nitrogen is present in most biomass forms, ranging from trace amounts in wood to about one percent in cereal grain straw and two to three percent in seaweeds.

Conversely, the inorganic component of biofuels varies widely. The inherent ash content, which is an integral part of the plant structure and consists of a wide range of elements, represents less than a half percent in wood, five to 10 percent in many agricultural crop materials, and up to 30 to 40 percent in, for example, rice hulls and millfoil.

In addition, during growth, harvest, transport and processing, biomass often accumulates substantial quantities of inorganic contaminants such as rocks, metal, sand and earth. The erosive action of these components on biomass feedstocks can cause slagging during high temperature conversion processes.

As a result of federal R,D&D efforts, significant advances have been made in quantifying the basic thermodynamic and physical characteristics of biofuels. However, substantial research is still needed. Basic engineering information on bulk density, strength and flow properties is required to develop guidelines for the design of preparation and handling systems.

The National Research Council of Canada and the U.S. National Bureau of Standards have jointly proposed the use of biomass reference samples to provide a standard of comparison for chemical conversions. Canada has provided funding for the collection and preparation of standard wood chips to help coordinate work being carried out by IEA researchers in different countries.

## 3.3 MEASUREMENT

The control of fuel flow by continuous, automated weight determination is standard practice in industry. With biofuels, however, not only weight but also fuel moisture content must be determined to ensure complete control over the efficiency of the conversion process. In hog fuel boilers, supplementary fossil fuels are often utilized to maintain full capacity steam generation. Overestimating the moisture content can result in unnecessary usage of fossil fuels and increase the overall cost of steam production.

Similarly, underestimates can contribute to poor furnace operation and unacceptable pollution levels.

The traditional means of determining biofuel moisture content is the oven-dry method. Although accurate, this method is slow and relies on the use of small samples which may not accurately represent the actual process fuel. Due to the high moisture content variation possible in biofuels and the growing trend toward conversion process automation, Canada's R,D&D efforts have been directed toward the development of reliable, continuous moisture measuring equipment.

PPRIC

With federal support, the Pulp and Paper Research Institute of Canada (PPRIC) evaluated two commercially available infrared analyzers for their ability to measure hog fuel moisture content [project ref. 3.2]. Good results were obtained when the moisture tests were conducted under carefully controlled laboratory conditions. However, the instruments were found to be very sensitive to hog fuel quality, particularly particle size, which limited their practicality in a continuous, industrial process. Since the study, the manufacturers of the infrared analyzers have improved the device and several industrial systems using hog fuel are now in place.

W & Y Consultants

Other federally funded work has concentrated on the development of new equipment for biomass moisture content determination. In one project, W & Y Consultants Kingston Ltd. developed a small-scale, on-line moisture meter that uses microwave technology [project ref. 3.3]. The prototype equipment, tested using wood chips in a laboratory environment, had a reproducibility of better than three percent in the 10 to 50 percent moisture content range.

Carleton University

In other federally sponsored projects, radio frequency (RF) equipment was developed and tested for moisture content determination of various biomass materials. At Carleton University, RF moisture content determinations were obtained using static biomass samples [project ref. 3.4]. Subsequently, Avtech Electrosystems Ltd. developed an RF moisture content testing procedure using simulated conveyor movement [project ref. 3.5]. While the RF sensors tended to be displaced by vibrations in the conveyor system, Avtech is hopeful that future work will render the equipment suitable for industrial use.

Avtech Electro-systems

Forintek

In another study recently completed under the Bioenergy Development Program, researchers at Forintek Canada Corp. constructed and tested a biofuel moisture determination system using infrared heaters and point sensors [project ref. 3.6]. In this method, a known amount of heat is applied to a biomass sample and the surface temperature rise is measured and correlated to actual moisture content.

Forintek conducted laboratory tests using various depths of hog fuel, sawdust, planer shavings and wood chips under simulated conveyor movement. In general, temperature rise and actual moisture content correlated well. The infrared system was also effective in determining the moisture content of frozen hog fuel. To account for differences in sample depth and particle size in mill applications, researchers have proposed the use of calibration lines and tables for individual fuel types. For accurate on-line moisture measurement, researchers also recommend the use of line-scanning rather than point-scanning techniques.

## 3.4 UPGRADING

### 3.4.1 Drying

The moisture content of biomass is highly variable, depending on the specific type of material, the time since harvest, the storage conditions, and the degree of pretreatment applied. Even within a narrow fuel type, such as hog fuel (the most widely used solid biofuel) moisture content can vary significantly. For example, debarker residues may have moisture contents of up to 70 percent, while those of shavings and sawdust from dry lumber processing may be only 10 to 20 percent.

Drying biofuels prior to utilization greatly increases their recoverable energy. Direct combustion -- the most commonly used energy conversion process -- is adversely affected by high moisture content in at least three ways:

* Since energy is needed for evaporation, high moisture content lowers the potential energy of the biomass and subsequently lowers the overall process efficiency.

* Dry biomass burns at higher temperatures, resulting in more complete combustion and less particulate emission.

* High or fluctuating moisture levels often necessitate the use of an auxiliary fuel such as oil to assist in combustion. In addition to the extra operational costs, the use of an auxiliary fossil fuel results in emissions of sulphur dioxide and sulphur trioxide.

Commercial drying systems can be either thermal or mechanical. In thermal drying, moisture is evaporated from the wet biomass using waste flue gas, heated air, or steam. Typical commercial flue gas dryers include the rotary, cascade and flash types. The choice of dryer depends mainly on the physical characteristics of the biomass, space constraints, the desired final moisture content, and capital availability. Rotary and cascade dryers are normally used to

dry materials of up to 75 mm in diameter with a moisture content of 45 to 65 percent to a final moisture content of 30 to 40 percent. Flash dryers are used to dry 2 mm diameter and smaller material to a final moisture content of about 10 to 15 percent.

Mechanical dewatering is commonly used for the partial drying of biomass materials containing large amounts of water. Typical dewatering devices use either rollers, chains, rams, or screws to apply intense pressure to the wet materials. After pressing, the moisture content of the biomass is usually reduced to 55 - 60 percent. Some new generation presses using perforated drum designs can achieve final moisture contents of 45 to 50 percent.

Stake Technology

With federal support, Stake Technology Ltd. evaluated the potential of a modified high-pressure feeder for the mechanical dewatering of forest biomass [project ref. 3.7]. The pilot-scale unit successfully dewatered about 2.3 tonnes of wet bark per hour, reducing the final moisture content to about 50 percent. Dewatering action was achieved through the application of rapid compressive forces imposed by a reciprocating annular piston concentric with a screw pre-press.

With further federal assistance, Stake is currently constructing a prototype commercial-scale dewatering device with a capacity of about 100,000 tonnes of wet bark per year. Commercial-scale testing is expected to take place at a pulp mill.

Sandwell & Company

In another project, Sandwell and Company Ltd. examined the economic potential of using flue gas or steam for the drying of hog fuel [project ref. 3.8]. The study described and compared five different types of commercially available wood waste dryers according to factors such as capital cost, operational characteristics, drying capabilities and particle size requirements. Economic analyses showed that it is usually uneconomic to add a dryer to a modern boiler designed to burn fuel with a moisture content of about 60 percent. However, for older less efficient systems, the benefits are often great enough to warrant retrofit dryer installations.

The Sandwell study has received considerable interest from industry and remains a valuable reference for information on the economics of flue gas drying. Commercial interest in this technology appears to be high, the number of industrial installations having doubled since the time of the study.

PPRIC

With federal sponsorship under the ENFOR Program, the Pulp and Paper Research Institute of Canada has investigated the potential for another drying process -- vapour recompression [project ref. 3.9]. In this process, vapours generated during drying are compressed and returned to the system to supply most of the heat requirement by indirect condensation. The

driving force for heat transfer is provided by the high condensation temperature of the compressed vapours. The net energy savings are high since there is no loss of latent heat -- the moisture in the wet biomass leaves the system in liquid form.

Initial experiments established that the heat transfer coefficient for a direct contact dryer (solid biomass in contact with the heat exchange surfaces) was too low to warrant further consideration and PPRIC began investigating the use of tall oil, a by-product of kraft pulping, as a heat transfer agent to improve the drying rate. Bench-scale tests showed that, with the oil medium, the heat transfer coefficient was increased to two or three times its original value.

Based on this work, PPRIC constructed a continuous, pilot-scale drying unit with the capacity to handle several kilograms of hog fuel per hour. In the system, wet feedstock was mixed with the hot oil and circulated through a vertical, steam-jacketed heat exchanger. Water vapour was separated in a flash tank and the oil/hog fuel mixture was routed to a settling tank where particles that had dried to less than 25 percent moisture content settled out and were withdrawn through a screw press.

Typically, the dried hog fuel had a moisture content of 10 to 20 percent and an oil content of 15 to 20 percent. Densification trials were carried out on the dried hog fuel using commercial ram and screw presses and briquettes of intermediate quality were produced.

While the economics of the pilot-scale plant were borderline, a larger-scale unit might be economically viable. It has not yet been decided whether further research will be carried out on this technology.

### 3.1.2 Comminution

Another area of federal involvement, comminution is required for effective utilization of many forms of solid biomass fuels, particularly those derived from the forest. The method used depends on the size requirements of the end product and the properties of the material being processed.

For some conversion processes, such as suspension burning, finely comminuted feedstock materials are required. Fine particle size ensures good fuel distribution, a uniform rate of heat release, and good system control. Other conversion systems, such as hog fuel boilers, can tolerate relatively large fuel particles, although the fuel delivery system may dictate a maximum size limitation. Household stoves and small manually fed commercial furnaces can accept relatively large fuel chunks.

Equipment used for the size reduction of biomass fuels can be roughly grouped into four categories:

Cutters: The initial reduction of large individual biomass components such as logs, stumps and tree branches is achieved through the use of saws, shears, slicers and splitters. These reduce large pieces to a manageable size for ease in transport and handling or for feeding into equipment for further size reduction. In the case of stovewood production for home heating, cross-cutting by saw or shear and splitting constitute the only size reduction required for the final fuel product.

A new development by the U.S. Forest Service -- the involuted disk slicer, uses curved cutting blades to produce chunkwood by cross-cutting small-diameter logs. The product, substantially larger than standard pulp chips, can be used as a prepared fuel or an intermediate product prior to further processing.

Chippers: Chippers employ a cutting or slicing knife action to reduce whole-tree material or solid wood residuals to fuel chips of relatively consistent length. The rotating knives, mounted either on the face of a disk or the periphery of a drum operate against a fixed anvil. Since their performance depends on blade sharpness, chippers are best used to comminute material which is free of dirt, rocks and metal.

Hammermills: Widely used for the production of particulate fuel from woody materials, hammermills (or hogs) employ rotating hammers or knives operating against fixed anvils or impact plates and normally include a fixed screen. Their crushing/tearing action results in a random-sized fuel, the maximum dimension of which is dictated by the screen opening.

Typically, these machines are used to reduce relatively large unsorted materials into hog fuel chunks of less than 75 mm in diameter. Pulverizers can then be used to process the hog fuel to fine residues for suspension burning, densification, or processing into prepared fuels.

While hammermills have a greater tolerance for dirt and inorganic impurities than do chippers, they still require protection from tramp metal and large rocks.

Shredders: Developed specifically to handle coarse materials containing large quantities of impurities, shredders feature rugged construction and low rotational speeds. They rely on a crushing/tearing action and are often used to process municipal and industrial wastes, as well as log sort-yard debris.

Initiated under ENFOR and expanded under the Bioenergy Development Program, federally supported projects have addressed several aspects of biomass comminution.

Inproheat Industries

In one project, Inproheat Industries Ltd. of Vancouver, B.C., constructed and tested a 1,000 kg/h (wet fuel) pilot plant for the production of fine, dry fuels for suspension firing in large boilers [project ref. 3.10]. The pilot plant used a commercial pulverizer for particle size reduction and low-temperature waste flue gas for product drying. This principle of fuel preparation is now being used in several industrial applications.

General Comminution Inc.

Another recent development in the field of comminution is the Szego mill, a novel planetary ring-roller mill. Due to the mill's proven success in fine-grinding materials such as coal, minerals and chemicals, federally supported research was initiated to evaluate the system's effectiveness with wood and bark materials.

Under the sponsorship of the Bioenergy Development Program, General Comminution Inc. of Don Mills, Ontario, is optimizing the performance of the Szego mill on wood and bark residues under laboratory conditions [project ref. 3.11]. Critical factors such as roller groove design and product classification will also be evaluated. In the project's second phase, researchers plan to install a larger pilot-scale Szego mill at a pulp and paper facility. The unit will be tested for the production of suspension burner fuel.

University of Toronto

The University of Toronto has also conducted research on the Szego mill. There, a pilot-scale (23 cm diameter) was tested using wood and bark of both high and low moisture contents in [project ref. 3.12]. Basic factors affecting the mill's performance were evaluated, including rotational speed, feed rate, and number of passes through the mill. It was found that the mill was capable of fine-grinding wood and bark, although the system's performance was tied to moisture content. The mill's energy requirements were found to be comparable with, if not lower than, the most efficient wood-grinding equipment currently in use.

Although the Szego mill is not yet commercially proven for biomass materials, Canadian and international interest in the unit is high. The mill may be particularly well suited to Scandinavian operations, in which it is common practice to grind biomass to fine sizes before conversion. Attractive features of the unit are its low wear characteristics and low energy requirements.

FERIC / TVA

As part of a federal program to assess the harvesting of logging residues and forest residuals for fuel, the Forest Engineering Research Institute of Canada (FERIC) examined the potential of using roll-splitters to crush roundwood bolts

into intermediate-sized materials suitable for baling [project ref. 3.13].

An improved unit was developed and the prototype roll-splitter tested in a joint venture between FERIC and the Tennessee Valley Authority (TVA) [project ref. 3.14]. The major objectives of the project were to evaluate the dewatering ability of the roll-splitter and to assess the air-drying characteristics of the resulting residues. The study team found that the roll-splitter had limited potential as a dewatering device, removing a maximum of only nine percent of the original moisture. However, the crushed residues air-dried much more rapidly than uncrushed material. After five days of air drying, the average moisture content of crushed materials was reduced to about 25 percent of the original moisture. Roundwood material showed little change in moisture content during the same time period.

### 3.4.3 Classification

For most energy applications, particularly for conversion to liquid or gaseous prepared fuels, biomass materials must be classified by particle size and cleaned to remove unwanted inorganic materials. Classification and cleaning not only improve the overall handling characteristics of the fuel, but also reduce the risks of damage to processing equipment and contamination of chemical reactions.

In most commercial operations, mechanical screens are used to separate and redirect the flow of oversize or undersize material. Magnetic devices are used to remove ferrous materials. For removal of sand and rocks, most commercial devices rely on techniques which differentiate between the densities of the foreign material and the biomass fuel. Many of these commercial systems, however, are ineffective in removing the high concentrations of inorganic matter commonly present in biomass fuels.

B.C. Research

Under the Bioenergy Development Program, B.C. Research of Vancouver is constructing a vacuum drum system to separate foreign matter from log sort-yard residues [project ref. 3.15]. The pilot-scale unit will have a capacity of 10 to 30 cubic metres of residue per hour and will be tested using biomass materials 50 mm or less in diameter. Preliminary testing has already been conducted to optimize the performance of a lab-scale vacuum drum. When completed, the study should generate sufficient data to derive guidelines for a multi-stage separator system suitable for a wide range of particle sizes.

### 3.4.4 Compaction

Compaction is a proven technology in the agricultural, recycling, and waste disposal industries. In contrast to densification, which results in a prepared fuel product, compaction is a process by which the bulk density of raw biomass materials is increased to facilitate handling and transportation prior to further processing.

FERIC

Considerable federal research effort has been directed to the use of compaction techniques for improving the energy density and handling characteristics of logging residues. This effort was spearheaded by a state-of-the-art review of all types of available compacting systems, including baling, container compaction, on-truck compaction, and bundling devices [project ref. 3.14]. The report, compiled by FERIC, notes that most compacting systems have been tested on forest biomass and that baling appears to be the most promising technique.

K.C. Jones & Associates

In particular, a prototype baling unit developed at the Virginia Polytechnic Institute appears to be well suited to Canadian applications. This prototype baler was tested by K.C. Jones & Associates under contract to FERIC. Green spruce logging slash with an oven-dry bulk density of about 80 kg/cubic metre was compacted to a bulk density of 160 kg/cubic metre, thereby cutting the volume requirements for storing and transporting the material by half.

CRIQ

A Bioenergy Development Program project under way at the Centre de Recherche Industrielle du Quebec (CRIQ) in Ste-Foy, Quebec, proposes the use of residue baling and air drying in conjunction with roadside delimbing and topping [project ref. 3.16]. Roadside processing eliminates the need to collect scattered residues from the forest floor.

In the study, experimental bales will be made from green comminuted forest residues at various levels of pressure. After compaction, the bales will be air-dried to a bulk density of about 400 kg/cubic metre. This target figure represents the optimum density for cost-effective trailer transport. In addition, economic and design work will be conducted for a mobile logging residue hogging/baling system with a capacity of 100 tonnes per day.

## 3.5 MATERIAL TRANSFER

In a biomass conversion plant, many different types of equipment are used to transfer biomass materials from one processing operation to the next. Front-end loaders are often used for short-distance manoeuvers within the plant yard, and for building outdoor storage piles; conveyors are used for primary transport, such as delivery to a storage silo; and

feeders are used to regulate the flow of materials to the final conversion operation of between processing stations. The choice of conveying system depends on the physical nature of the biomass material, the transfer distance and slope, and the required operational speed.

Conveyors can be either mechanical, i.e. chain, belt, or bucket elevator, or pneumatic in design. In the case of pneumatic feeders, for example, materials are air-blown through a metering device or valve. Mechanical feeders are usually of the screw, belt, or continuous grate types. Typically, mechanical designs are used for the transfer of relatively coarse materials, whereas pneumatic designs are well suited to the movement of fine materials.

B.C. Research

Under a three-year ENFOR project, B.C. Research developed, constructed, and tested a 5 t/h pneumatic hog fuel conveying device [project ref. 3.17]. This novel piece of equipment requires less air and less power to achieve material movement than do conventional systems. Since the hog fuel particles are not carried in suspension, but are conveyed as discrete "slugs" at relatively slow speeds, this new system should significantly reduce operational costs and virtually eliminate the problem of pipe wear.

According to B.C. Research, further developmental work must be conducted before the system is commercialized. Work is under way to facilitate the movement of coarser fuel particles and increase overall system capacity.

Logging Development Corp.

In Central Europe, Scandinavia and the U.S.S.R., efforts are being directed at the use of full-tree hauling and processing to maximize use of the forest resource base. Full or partially delimbed trees are transported in specially designed trailers to the mill where the production of sawlogs, pulpwood and energy material can be controlled and optimized. In this system, higher hauling costs are compensated for by increased yield. These practices, in their early stages in Europe, are commonly practiced in the U.S.S.R. where the recovery of coniferous foliage for conversion to high-value animal feed supplement is commonplace.

With federal support, Logging Development Corporation (LDC) of Montreal, Quebec, has designed a central full tree processing complex to optimize utilization of the forest resource [project ref. 3.18]. In this system, full trees are trucked to a central location for delimbing, slashing and residue segregation and collection.

In the first phase of this project, design and economic data were determined for a processing complex with a capacity of 280,000 cubic metres of roundwood per year. In the second phase, field tests were conducted to show that full trees could be handled and transported at acceptable production

rates. It was found, however, that conventional hauling equipment could only handle about one-half of the load possible with tree-length material. To overcome this difficulty, LDC proposed the use of an extended, partially enclosed trailer equipped with a compactor to compress the bulky segments of the tree. In conjunction with FERIC, LDC is currently conducting further work on the design of a suitable trailer.

Biomass Combustion Ltd.

Federal support under the ERDAF program led to the development of a novel feed mechanism for straw burners. After considering various configurations for bale break-up, stoker transfer, and back-burn prevention, Biomass Combustion Ltd. of Canning, N.S., designed and constructed a suitable system and is now monitoring its performance [project ref. 3.19].

## 3.6 STORAGE

To accommodate the handling of bulk biomass materials, it is usually necessary to have some storage capacity. Outdoor piles are often used to store wood-based particulate fuels obtained from primary processing. In many cases, it is not possible to utilize the materials immediately and a significant time period may elapse before reclamation. Although outdoor storage has been practised by the industry for many years, concerns over changes in fuel quality during storage have only recently been addressed.

Forintek

With federal funding, Forintek Canada Corp. conducted a literature review to assess changes that could occur in an exterior storage pile [project ref. 3.20]. The study proposes alternative storage techniques to maximize the fuel characteristics of the stored materials. The report presents data obtained primarily from studies conducted on the storage of pulp chips and addresses the following topics: moisture content changes, heat development and spontaneous ignition, loss of wood/bark substance, changes in heating value, microbial causes of deterioration, methods of preventing storage losses, and environmental issues.

The report recommends that outside fuel piles be managed in such a way as to minimize storage losses and reduce the risk of spontaneous ignition. A variety of techniques can be used to maximize the fuel value of stored materials, including proper material rotation (i.e. last in, last out), control of pile size, minimizing undersize materials, predrying, and monitoring of pile temperature.

Forintek's study is complemented by a recently completed Virginia Polytechnic Institute investigation into the effects of outdoor storage on the fuel properties of wood and bark particulates. Based on the available data, the Virginia study

concludes that engineering guidelines could now be developed for outdoor storage practices.

B.H. Levelton & Associates

Other federal research has investigated vertical retaining wall design. Used to keep biomass fuel piles within manageable size limits, most retaining walls have been built using design data obtained from other materials, usually soils and fills.

In one federal project, B.H. Levelton and Associates Ltd. conducted field tests at two industrial locations to determine the effects of various loading conditions on the lateral forces exerted by hog fuel piles [project ref. 3.21]. Using special pressure-sensing and recording equipment, it was found that factors such as biomass type, pile age, pile depth, and vehicular traffic attributed to variations in lateral pressure. The report provides much of the background information needed by engineers for the design of biomass fuel retaining structures.

While vertical retaining walls provide relatively long-term storage of biomass materials, conversion plants also require bins or silos for short-term storage purposes. Large bins or silos are often used to store a few days supply of feedstock, normally to carry the plant over a long weekend. Smaller bins may have storage capacities ranging from a few minutes to a few hours. Regardless, their purpose is to help maintain and control the plant's internal feedstock flow.

Due to the extreme heterogeneity of biomass fuels, conventional storage bins and silos commonly experience feedstock discharge problems. As a result, flow stoppages and operational disruptions often occur. Bridging, funnel flow, and piping are typical flow problems associated with the gravity discharge of biomass fuels.

B.C. Research

Under a four-year federal study, B.C. Research generated fundamental data for the development of bin and silo design guidelines [project ref. 3.22]. Laboratory tests showed that a mass flow hopper design with smooth, steep walls was needed to ensure the adequate flow of most biomass fuels. This type of design would ensure a reliable flow of material using gravity alone and would minimize bin outlet dimensions.

To facilitate mass flow, B.C. Research proposed the use of an ultra high molecular polymer (UHMP) liner to reduce friction. An experimental 80 cubic metre gravity flow bin with adjustable slope and outlet width was constructed. Initially, the unit was tested using a gravity discharge mechanism and it was found that the results agreed well with laboratory predictions.

Further testing was conducted using screw and belt discharge feeders. The screw feeder performed satisfactorily provided that adjustments were made to minimize packing of the fuel at

the front wall of the bin. The specially designed, non-consolidating belt feeder provided a uniform discharge with very low power requirements. B.C. Research is currently working on another project in Thunder Bay, Ontario, to improve an existing storage bin. The bin will be lined with UHMP and modified to permit mass flow discharge.

## 3.7 Ddensification

Densification is a process in which high pressures are applied to biomass residues to produce a fuel product with predictable and enhanced properties, including high bulk density, uniform size, relative cleanliness and superior combustion characteristics. Densification results in a threefold to fourfold increase in energy density as compared to unprocessed forest biomass fuels.

Densification is a commercially-proven process and a wide variety of equipment is available for most biomass materials. Commercial densification systems require clean, finely-comminuted feedstock dried to a moisture content of about 10 to 20 percent. Densified fuels can be categorized according to the size and shape of the product or the type of equipment used in the production process, e.g. logs, briquettes, cubes and pellets.

The most well-known densified biomass fuel product is the fireplace log. These logs are formed by machines known as extruders that force ground residues through cylindrical dies under high pressure. Typically, densified logs are about 30 cm long and 5 to 10 cm in diameter.

Smaller in size than firelogs, briquettes are formed using the same type of densification equipment. Briquettes measure approximately 5 to 10 cm in length and 2.5 to 5 cm in diameter, while cubes range from 2.5 to 5 cm on each side. The production of briquettes and cubes is not a large industry in Canada at present.

Bioshell Inc.

High production pellet mills are most commonly used for the manufacture of industrial densified fuels. A typical pellet mill consists of a rotating circular die with pressure rollers that force the residues through small openings in the die. Typically, pellets are about 13 to 38 mm in length and 6 mm in diameter. The largest manufacturer of densified fuels in Canada is BioShell Inc., which produces fuel pellets under the trade name Energex. Although the fuel pellet is available for domestic heating, Energex is used almost exclusively for powering industrial boilers.

The major disadvantage of densified fuels is their low water resistance. They can disintegrate quite rapidly when exposed to conditions of high humidity and, as a result, must be

stored in enclosed shelters and transported in covered trailers. Studies to improve the water resistance of densified biomass fuels have been initiated under both the Bioenergy Development Program and ENFOR.

B.H. Levelton & Associates

In an in-depth study, B.H. Levelton and Associates Ltd. examined the basic processing conditions required to produce a water-stable densified product from forest biomass [project ref. 3.23]. Optimum pressures, temperatures and feedstock moisture contents needed for water resistance were determined for various species and types of forest biomass materials.

Under the Bioenergy Development Program, further work will be carried out in this area. B.H. Levelton and Associates will conduct pilot-scale tests to determine the suitability of a board press and an extrusion machine for the production of densified fuels [project ref. 3.24]. The results of the testing should provide information to design a commercial plant.

Ontario Research Foundation

Two other Bioenergy Development Program projects are also aimed at improving the water resistance of densified fuels. At the Ontario Research Foundation, efforts are being directed at improved water resistance through the use of inexpensive natural and synthetic binders [project ref. 3.25].

K.C. Shen Technology

As well, researchers at K.C. Shen Technology International Ltd. in Ottawa, Ontario, are examining the use of a pressure device coupled with steam injection to impart water resistance [project ref. 3.26].

## 3.8 SUMMARY

Most biomass materials are difficult to collect, transport, store, handle and feed into conversion reactors. Despite these limitations, Canadian industry has developed proven commercial systems for the production of high value biomass products. With the growing interest in the recovery and handling of biomass for energy purposes, federal R,D&D has focused on the modification of established technologies for biofuel production as well as on the development of new equipment and systems.

A major objective of federal projects has been, and continues to be, that of cost-effectiveness, both in reducing the high capital and operating costs of biomass-to-energy conversion equipment and in improving the efficiency and reliability of feedstock collection, transport and preparation mechanisms. Many projects have focused on small-scale bioenergy applications. Since large conventional systems cannot always be effectively down-scaled, researchers have sought to improve the availability of reliable small-scale equipment.

Canadian R,D&D has also addressed biomass feedstock quality. The classification and sorting of biomass materials, the development of stringent comminution and segregation processes, and the elimination of contaminants have reduced handling problems to the point where traditional systems can often operate effectively on biofuels with little modification.

Finally, as the use of biomass for energy extends beyond on-site use at pulp and paper operations to residential, commercial and institutional applications, the Federal Government is publishing information to increase the level of public awareness concerning bioenergy systems.

## 3.9 FEDERAL PROJECT REFERENCES


3.1 "Determination of Available Heat of Combustion Data for Canadian Woody Species", Forintek Canada Corp., Ottawa, Ont., 1983-84.

3.2 "Evaluation of Infrared Moisture Analyzers for Hog Fuel", Pulp and Paper Research Institute of Canada, Pointe Claire, Que., 1980-81.

3.3 "Development and Small-Scale Demonstration of a Reliable On-Line Monitor for the Continuous Measurement of Feedstock Moisture Content", W & Y Consultants Kingston Ltd., Kingston, Ont., 1980-81.

3.4 "RF Transmission Line Method for Feedstock Moisture Content Determination, Phase I", Carleton University, Ottawa, Ont., 1980-81.

3.5 "RF Transmission Line Method for Feedstock Moisture Content Determination, Phase II", Avtech Electrosystems Ltd., Ottawa, Ont., 1981-82.

3.6 "Evaluation of a New Moisture Measuring Method for Determining On-Line Moisture Content in Biomass Feedstocks", Forintek Canada Corp., Vancouver, B.C., 1984-85.

3.7 "Design, Construction, and Testing of a Bark Dewatering Device", Stake Technology Ltd., Ottawa, Ont., 1978-79.

3.8 "Cost Benefit Analysis of Gas Drying Systems for Wood Waste Feedstocks", Sandwell & Company Ltd., Vancouver, B.C., 1980-81.

3.9 "Hog Fuel Drying Using Vapour Recompression", Pulp & Paper Institute of Canada, Pointe Claire, Que., 1981-82.

3.10 "Advanced Feedstock Preparation System for Large-Scale Hog Fuel Boilers", Industrial Process Heat Engineering Ltd., Vancouver, B.C., 1980-81.

3.11 "Grinding of Wood Chips and Bark to Fine Powders -- Phase II", General Comminution Ltd., Don Mills, Ont., 1984-85.

3.12 "Grinding of Wood Chips and Bark to Fine Powders -- Phase I", University of Toronto, Toronto, Ont., 1983-84.

3.13 "Development of a Roll-Splitter", Forest Engineering Research Institute of Canada, Pointe Claire, Que., 1981-82.

3.14 "Development of Forest Biomass Compaction System", Forest Engineering Research Institute of Canada, Pointe Claire, Que., 1984-85.

3.15 "Development of a Vacuum Drum Separator for Dirt and Rocks from Biomass", B.C. Research, Vancouver, B.C., 1984-85.

3.16 "Crushing and Compacting System for Forest Waste", Centre de Recherche Industrielle du Quebec, Ste-Foy, Que., 1984-85.

3.17 "Development of a Dense Phase Pneumatic Conveying System for Biomass Materials", B.C. Research, Vancouver, B.C., 1982-83.

3.18 "The Development of Machinery for the Recovery and Preparation of Biomass Feedstocks for Conversion Systems at a Central Full Tree Processing Complex", Logging Development Corp., Montreal, Que., 1981-82.

3.19 "Development of a Feed Mechanism for Straw Burners", Biomass Combustion Ltd., Canning, N.S., 1983-84.

3.20 "Fuel Value of Stored Forest and Mill Residues", Forintek Canada Corp., Ottawa, Ont., 1981-82.

3.21 "A Study of Forces Exerted by Hog Fuel Piles on Restraining Structures", B.H. Levelton & Associates Ltd., Vancouver, B.C., 1981-82.

3.22 "Bin and Silo Design for Biomass Materials", B.C. Research, Vancouver, B.C., 1980-81.

3.23 "Development of a Moisture Resistant Densified Solid Fuel from Forest Biomass", B.H. Levelton & Associates Ltd., Vancouver, B.C., 1980-81.

3.24 "Development of Equipment to Produce Moisture Resistant Densified Solid Fuel from Biomass Residues", B.H. Levelton & Associates Ltd., Vancouver, B.C., 1984-85.

3.25 "Development of a Moisture Resistant Densified Solid Fuel from Forest Biomass", Ontario Research Foundation, Mississauga, Ont., 1984-85.

3.26 "Development of a Waterproof Densified Solid Fuel Log from Forestry Residues", K.C. Shen Technology International Ltd., Ottawa, Ont., 1985-86.

# CHAPTER 4

# DIRECT COMBUSTION

# CHAPTER 4

# DIRECT COMBUSTION

## 4.1 INTRODUCTION

THE BURNING of biomass -- more technically, its direct combustion in an excess of air -- is a process that is well known and well understood. Reliable, proven equipment with warrantied performance and durability is readily available for many applications.

The direct combustion of biofuels is used in most sectors of Canadian life. Applications range from small stoves used for domestic space heating to multi-storey, computer-controlled power boilers used for the cogeneration of electricity and process steam. Fuels range from dry powder to half-tonne bales and include wood and wood-derived residues, agricultural and food processing residues, municipal wastes and peat. Direct combustion often serves a dual function, that of generating process energy and that of effective disposal of industrial, commercial and domestic residues.

For large-scale biomass-fired combustors to compete economically with traditional oil and gas systems, biomass fuels must be available at little or no cost. Thus, federally supported R,D&D into large-scale combustion systems has focused on the increased use of forest-derived residues within the pulp and paper sector. The firing of lime kilns and the over-firing of hog fuel boilers are two areas receiving support. In addition, an in-depth boiler test program is providing valuable information on process control, performance and emissions.

Federal initiatives in medium-scale combustion have centred on the conversion of existing oil and gas-fired combustion systems to biomass. Projects have included retrofits on hospitals, greenhouses, schools, universities and commercial/industrial facilities.

In small-scale combustion, the Federal Government has supported the demonstration, testing and monitoring of residential and small commercial wood heating devices, as well as the development of codes and standards.

## 4.2 LARGE-SCALE COMBUSTION

Large industrial biomass combustion systems are characterized by having an integral combustor-boiler with a complete or partial water-wall furnace. These units, which can be several stories high, are usually constructed on-site and are specifically designed for the production of high-pressure, superheated steam. Typically, they have outputs of 50,000 to 200,000 kg/h and burn relatively unprocessed fuels on a grate with high temperature under- and over-fire air. Modern units are fully automated and operate continuously. Large-scale combustors are generally categorized according to the type of grate employed: horizontal travelling, flat, pin-hole, steeply sloped pin-hole, or sloped reciprocating grate.

Recovery Boilers: Pulp mill recovery boilers generate more energy than any other single bioenergy application in Canada. These specially designed large-scale systems burn spent pulping liquor to recover chemicals for recycling and to provide steam for in-house thermal and electrical loads. The liquor, which contains dissolved wood lignin, is dried from 15 - 18 percent to 65 - 70 percent solids in multiple-effect evaporators, and then sprayed into the recovery furnace for final drying and combustion. Recovery boilers account for over one-third of the total primary energy requirement of the Canadian pulp and paper industry, or about 200 million gigajoules per year.

Hog Fuel Boilers: Hog fuel boilers account for seven percent of the pulp and paper industry's primary energy demand (about 40 million GJ/a). These units produce up to 180,000 kg/h of steam by burning hog fuel -- a mixture of bark, sawdust, chip fines, clarifier sludge and other wood-derived mill residues. Minimal fuel preparation is necessary. Feedstocks are usually hogged to a maximum diameter of eight centimetres and mechanically dewatered to about 55 to 60 percent moisture content.

Municipal Solid Waste Boilers: Large-scale boiler systems are also used for the bulk burning of municipal solid waste (MSW) and the semi-suspension burning of refuse-derived fuels (RDF), the light fraction of MSW. Capable of incinerating over 250 tonnes per day of refuse, these boilers feature reciprocating or travelling grates. In Canada, large-scale energy-from-waste facilities are currently operating in Quebec City, Montreal and Hamilton.

The large-scale combustion of biomass fuels has been tested in a number of industrial settings, including lime kilns, pulp mill hog fuel boilers and, to a lesser extent, cement kilns. With federal and provincial support, test runs have established the technical viability of using commercial-scale equipment to burn refuse-derived fuel, shredded rubber tires, flax shives, and pulverized wood residues. In addition, a

federally supported trial in Bishop's Falls, Newfoundland, has demonstrated the industrial firing of peat [project ref. 4.1].

### 4.2.1 Lime Kiln Firing

The firing of lime kilns is an area which offers considerable potential for fossil fuel substitution -- about three million barrels of oil equivalent per year. Federal research projects have been implemented to examine two avenues for substitution -- the in-situ combustion of relatively unprocessed hog fuel and the suspension-firing of dried pulverized fuel.

#### 4.2.1 (a) In-situ Combustion of Hog Fuel

Lamb-Cargate

One major federal project involved the construction and operation of a 63 GJ/h Lamb-Cargate wet-cell burner in Port Alberni, B.C. [project ref. 4.2]. The burner used hog fuel with a moisture content of 55 percent and supplied hot combustion gases at 1,200°C to displace oil in a 53 t/d lime kiln. Lime production levels were maintained with oil substitutions of up to 70 percent, with an energy efficiency of about 50 percent.

PPRIC

The concept of adding biomass fuels to the cold end of a lime kiln for direct combustion with the lime mud flow was developed by the Pulp and Paper Research Institute of Canada (PPRIC) [project ref. 4.3]. Preliminary trials were conducted in small-scale pilot kilns utilizing chips, hog fuel and pellets. Chemical analyses were carried out to determine the effects of in-situ combustion on lime quality and subsequent pulping liquor preparation.

The work culminated in a 20-day continuous test carried out on a 150 t/d industrial kraft mill lime kiln using wet screened hog fuel. An oil substitution of 35 percent was achieved with a fuel utilization efficiency of 53 percent. There were no noticeable deleterious effects on causticizing and pulping operations.

#### 4.2.1 (b) Suspension-Firing of Pulverized Biofuels

The suspension-firing of dry pulverized fuel in lime kilns is a proven and readily available technology. In fact, it is used on a commercial scale in Sweden. However, since the effects of inorganic contaminants on liquor preparation is site-specific, a federal study was undertaken to assess the potential for this technology at a typical Canadian bleached kraft mill.

Domtar Inc.

Domtar conducted the pilot plant pulping and bleaching studies at their Senneville, Quebec, facility using typical Canadian softwood chips and liquor samples obtained from a Swedish

mill [project ref. 4.4]. The liquor samples contained high levels of silicon and aluminum. The experiments showed that the presence of high levels of inorganic elements in the liquor produced from lime calcined in a wood-fired kiln does not significantly affect the pulping and bleaching response on Canadian chips. Application of this combustion process in Canadian mills should be straightforward.

### 4.2.2 Over-Firing of Hog Fuel Boilers

Another area of federal investigation is the reduction of oil and natural gas over-firing in hog fuel boilers. Typically, hog fuel boilers burn a significant quantity of oil or gas to stabilize combustion of the wet hog fuel, absorb peak loads and load swings, and take care of grate cleaning and hog fuel shortages. This fossil fuel requirement often accounts for up to 25 percent of the total boiler energy demand.

H.A. Simons Ltd.

A current project being carried out by H.A. Simons Ltd. of Vancouver, B.C., involves the modification of an existing oil burner on a hog fuel boiler to allow suspension-firing of dry, pulverized wood [project ref. 4.5].

### 4.2.3 Boiler Test Program

Although the direct combustion of biomass is a well established process, the inherent difficulties in burning low-quality, bulky fuels tend to discourage precise combustion control. This is particularly true in large hog fuel boilers, which were conceived more for incineration than for energy production.

To encourage more precise combustion control and thus reduce fossil fuel over-firing, the Federal Government initiated a major boiler test program [project refs. 6, 7]. Extensive field tests covering all aspects of boiler performance, including emissions, have been carried out on three units and testing on a fourth is under way.

Although test data is not yet available, it is reported that improvements made to boiler operating procedures as a result of the test program have resulted in yearly fuel savings of over $1 million for two of the boilers tested.

## 4.3 MEDIUM-SCALE COMBUSTION

Medium-scale combustion systems, generating in the range of 1,000 to 40,000 kg/h of steam, are characterized by a wide diversity in design, capability and application. Unlike

large-scale systems, they are usually package systems, manufactured at the plant and shipped as complete units or as major system modules for installation on-site. Only a few designs employ water-wall furnaces; most are equipped with refractory-lined combustion chambers.

Medium-scale systems can be classified into two major groups:

* Combustors: Combustors have a specific chamber in which the fuel is burned. The energy provided by the hot combustion gases can be used directly or can be transferred to a waste heat boiler/heat exchanger for the production of steam, hot oil, hot water or hot air.

* Package Boilers: These units contain an integral boiler section for the production of low-to-medium-pressure steam, hot water or hot oil. The boiler and combustor are usually separately defined sections.

### 4.3.1 Combustors

Available commercial combustors produce hot combustion gases at 500°to 1,300°C from a full range of biomass fuels including dry wood dust, unsorted MSW, wood chunks and prepared fuel pellets. They include simple, manually fed units with manual ash raking and tube cleaning, as well as fully automated units with microprocessor control.

#### 4.3.1 (a) Suspension Burners

Suspension burners require dry, pulverized, relatively clean fuel which is introduced into the combustion zone and burned while suspended in a flow of combustion air. Like traditional oil/gas burners, they feature quick start-up, fast response, good turn-down and high combustion efficiency.

Register Burners: Register burners utilize a very fine dry fuel which is mixed with the combustion air in the burner head and fired in a stable open flame. The burner can be mounted in a variety of combustor configurations and, in many cases, can directly replace an oil burner. Typically, register burners require up to 10 percent fossil fuel as a pilot to initiate and maintain combustion. Traditional applications include the firing of sanderdust in hot oil heaters at composite product plants.

Cyclonic Burners: Since cyclonic burners have a combustion chamber, they can operate on relatively coarse fuel (less than 40 mm diameter particles) with a high moisture content (up to 20 percent). The fuel is pneumatically injected in a tangential flow into a refractory-lined cylindrical combustor. An excess of preheated air is introduced to increase the cyclonic flow and complete the combustion

process. The combustor usually has a choke at the outlet to restrict particle emission until combustion is complete. After start-up, no pilot flame is required as the hot refractory stabilizes combustion. Cyclonic burners are often used to fire hammermilled dry shavings for the direct heating of lumber drying kilns or rotary driers.

Semi-Suspension Burners: Semi-suspension burning is a combustion process that can be utilized in package boilers, hog fuel boilers and MSW systems, among others. A shredded fuel with a range of fine to coarse particle sizes is pneumatically injected into the upper combustion zone. Fine material burns while suspended in the rising combustion gases; large particles fall to the bottom of the combustor and are burned on a fixed grate.

4.3.1 (b) Single-Chamber Combustors

Single-chamber biomass combustors, which evolved from residue incinerators, are usually simple in design. Typically, they feature a refractory-lined furnace with a bottom grate on which the fuel is burned. Primary air enters through the grate, while secondary air is delivered above the pile via over-fire ports. Single-chamber units can burn large batch-fed chunks or particulate fuels, which are usually introduced by means of a drop chute or a screw (or ram) feeder. Emissions are relatively high and problems can arise from the use of fine, dry fuels. High-moisture, low-quality fuels can be burned and maintenance/supervision requirements are low. A typical application is the burning of bagasse or mill yard residues.

4.3.1 (c) Multiple-Chamber Combustors

Multiple-chamber combustors involve at least two separate combustion chambers. A low-temperature, first-stage chamber is operated under starved-air conditions. The volatiles driven from the fuel pass through a choke to a second chamber where secondary air is supplied to complete high-temperature combustion. The two-stage approach greatly reduces particulate carry-over, producing a clean, hot gas output. These units offer high efficiencies and are well suited to high moisture fuels -- some designs can handle fuels of up to 60 percent moisture content. They have also been used successfully in the combustion of MSW and whole tree chips.

4.3.1 (d) Fluidized-Bed Combustors

A radical departure from traditional grate burning, the fluidized-bed combustor involves the combustion of fuel particles which are suspended in an air-dispersed bed of hot inert granular material, usually silica sand. Air is injected through a distributor plate and flows upward through the bed material, causing it to expand and adopt the characteristics

of a boiling liquid. The fuel, which is dropped or injected into the bed, burns while circulating within the hot sand.

Fluidized-bed combustors offer many advantages. Their high heat release rate means that even small units can provide relatively large outputs. In addition, their high thermal inertia means that a variety of fuels can be burned, including high-moisture, low-quality, and high-ash fuels. Fluidized-bed systems are often used to burn mill yard residues and clarifier sludge.

### 4.3.2 Package Boilers

Package boiler systems fall into two general configurations -- fire-tube and water-tube systems. Generally, fire-tube systems are small, low-pressure units in which the hot combustion gases pass through the inside of the boiler tubes. These tubes are located within a water-filled shell in which the steam is generated. In one design configuration, the combustion chamber is also located in a large tube within this shell.

For larger package boiler systems (greater than 14,000 kg/h) and higher pressure units (greater than 1.6 MPa), the water-tube configuration is most common. In this type of system, water flow and steam generation take place inside the boiler tubes, with the combustion gases flowing over the outside of the tubes.

The combustion section or furnace area of package boilers can employ any of the generic designs previously described under combustors, i.e., suspension or semi-suspension, single or multiple chamber, and fluidized-bed.

Package boilers have been successfully used for burning biomass in a wide variety of commercial and industrial applications. Traditionally used in the forest industries (sawmills, furniture plants, secondary wood working), they are now gaining acceptance in other areas, including food processing, hospitals, universities, schools, correctional institutes, armed forces bases, shopping centers, laundries and garages.

### 4.3.3 Technology Development

Federal Government support for medium-scale direct combustion has concentrated on technology development and demonstration.

Sandwell & Co. Ltd.

In one development project, Sandwell & Co. Ltd. of Vancouver, B.C., examined the feasibility of converting an existing fossil fuel-fired system to biofuels [project ref. 4.8].

Studies such as this provide a detailed outline of equipment requirements, operating and maintenance procedures, fuel supplies, storage requirements and fuel handling logistics. In-depth financial analyses can provide capital, installation and operating costs, as well as projected fuel cost savings and expected return-on-investment data.

To assist potential candidates interested in converting to biomass combustion, several federal studies have been undertaken to summarize the status of commercially available equipment and systems [project refs. 4.9, 4.10, 4.11, 4.12]. The resulting catalogues provide product specifications and supplier contacts, as well as estimated cost/benefit information.

In addition, under Agriculture Canada's ERDAF Program, a number of development trials have been carried out to test and modify combustors to burn cereal grain straw and other agricultural residues.

### 4.3.4 Demonstration Projects

The Federal Government has provided funds for many medium-scale combustion demonstration projects, often in cooperation with provincial, municipal or industrial programs. These demonstration initiatives fulfill the following objectives: to implement commercial prototype systems; to install and monitor systems from other countries; and to introduce the concept of bioenergy to potential users.

#### 4.3.4 (a) Hospitals

Several hospitals in New Brunswick, Newfoundland and Prince Edward Island have successfully converted from oil to wood residues and whole tree chips.

Of particular interest is a federally supported project in Parkdale, P.E.I. In this project, the combustion of municipal solid waste (MSW) provides steam to the Queen Elizabeth and Riverside Memorial Hospitals. The MSW is burned in a nearby energy-from-waste facility which has operated since 1983. The plant features three two-stage modular incinerators with a common exhaust header feeding into a heat recovery boiler. Each module disposes of 33 tonnes of refuse per day. The low-pressure steam is transferred by pipeline to the hospitals. Recent tests under the Federal Government's National Incinerator Testing and Evaluation Program (NITEP) have confirmed that emissions from the system are well below national standards.

4.3.4 (b) Greenhouses

Demonstration projects have also been supported in the greenhouse industry. Systems have been installed and monitored in Ontario, New Brunswick and Nova Scotia. Demonstrated fuels include wood residues, whole tree chips, and straw.

Gordon's Greenhouses in Oxford, N.S., a large producer of decorative floral crops, is one example of a company that has benefited from using bioenergy. The company required 1.2 million gallons of Bunker C oil per year to heat their facilities. In 1979, a wood waste handling system and three hot water boilers were installed. Fueled by high moisture content forest industry residues and locally chipped low-quality trees, the system has reduced oil consumption by over 98 percent.

4.3.4 (c) Educational Institutions

With federal support under various demonstration programs, many schools, colleges and universities in Ontario, New Brunswick, Prince Edward Island and the Yukon have converted from fossil fuels to biomass. Typically, large institutions install wood residue/whole tree chip combustion systems in an existing boiler house to supply steam or hot water for heating.

A new approach has been pioneered in a demonstration project at the Centre d'Education Evangeline in Abram Village, P.E.I. A portable wood-fueled heating plant was trucked to the site as a complete unit, placed on a slab foundation, and connected to the school's present heat distribution system. The heating plant is owned by a local forestry cooperative which sells the energy to the school.

4.3.4 (d) Commercial/Industrial Applications

Federal commercial/industrial demonstration projects in medium-scale combustion have covered a wide range of applications. Projects have included the burning of wood, straw and waste paper to heat homes and farm buildings, the burning of waste fish oil at fish processing plants, and the burning of methane to generate electricity at sewage treatment plants.

## 4.4 SMALL-SCALE COMBUSTION

In Canada, small-scale combustors of 0.5 to 2.0 GJ/h output account for the greatest number of bioenergy systems in operation today. They are used for two basic purposes -- household heating (either as supplemental room heating or as central heating, sometimes including water heating) and small

commercial applications, including garages, greenhouses, workshops, tobacco dryers and farm buildings.

Small combustors can be grouped into four categories:

* Stoves: Traditional cookstoves and the newer air-tight stoves consist of simple combustion chambers in which fuel is burned in a controlled air flow. The heat produced passes through the combustor walls for direct radiant heating of the surrounding area. Usually, stoves are manually fed with chunk wood, but models with automatic screw feeders for prepared fuel pellets or dry chips are also available.

* Furnaces: Furnaces involve a specific refractory-lined combustion chamber fitted with a close-coupled gas/air heat exchanger. The heat exchanger extracts heat from the combustion gases and circulates it via ducts to remote locations. Furnaces can be manually fed with chunk wood and baled straw or they can be fitted with an automatic stoker for particulate fuels such as chips, pellets and sawdust.

* Boilers: Similar in concept to furnaces, these units feature an integral hot water boiler for heat transfer.

* Preheaters: Preheaters were developed principally as a retrofit to allow the use of biomass fuel in existing oil/gas furnaces. Preheaters are small refractory-lined chambers that operate under starved-air conditions. The fuel volatiles driven off by combustion of the residual char pass through a refractory-lined duct into the furnace combustion chamber where secondary air is supplied to complete combustion. They are usually stoker fed on wet or dry chips or wood residue fuels.

Unlike medium-scale and large-scale systems, small-scale combustion units are often operated on an intermittent basis. If a continuous supply of heat is required, they can be fitted with heat storage systems and fired when convenient. Most small-scale systems require manual or semi-manual fuel supply and ash removal.

Federal support in small-scale direct combustion has covered the following areas:

* Demonstration: Under the Conservation and Renewable Energy Demonstration Agreements (CREDA) Program, a large number of small-scale units, principally chip-stoker and pellet furnaces, were installed in private homes and small commercial establishments to demonstrate the use of wood fuels as an alternative to central oil heat.

* Testing: Federal funding has also furthered the testing of furnaces, commercial and prototype stoves, and small-scale boilers. Studies have measured system efficiency, emissions and general performance, including safety and reliability.

Emphasis has been placed on the effects of different fuel types and moisture levels and on the effectiveness of various catalytic devices for hydrocarbon emission control.

* Monitoring: The Federal Government has been responsible for the intensive monitoring of commercial and prototype systems installed in private applications. Data on efficiency, emissions and performance has been collected and interviews carried out to determine general owner satisfaction.

* Codes and Standards: Together with the Canada Centre for Mineral and Energy Technology (CANMET), Energy, Mines and Resources has been very active in supporting the development of codes and standards governing the manufacture, installation and operation of small-scale biomass heating systems.

## 4.5 SUMMARY

In the pulp and paper sector, there are two main areas in which bioenergy could play a greater role: the over-firing of hog fuel boilers and the firing of lime kilns. The technology for firing dry pulverized biomass in suspension has been proven for both applications and equipment is commercially available. No serious technical problems have been identified and the technology could be readily implemented should economic conditions permit.

Similarly, the direct combustion of municipal solid waste is a proven technology. Available commercial equipment provides effective disposal and significant energy recovery.

Both hog fuel boilers and MSW combustion systems are constrained by the difficulties inherent in burning low-quality, heterogeneous fuels. Their performance is characterized by low efficiency, high particulate emissions, poor load-following capability, and high capital and operating costs. Continued federal efforts are aimed at improved performance through better fuel and combustion monitoring systems, greater information on basic combustion parameters, and improved combustor designs.

For medium-and small-scale combustion, the increased use of biomass as a fuel is limited where natural gas or low-cost hydro electricity is available. However, these technologies are economically justified for applications in which No. 2 oil is displaced and for which there is an abundant, low-cost source of biomass.

It is evident that technology constraints do not prevent the substitution of biomass for fossil fuels, since proven equipment is commercially available for most combustion applications. Federal R,D&D efforts continue to concentrate

on lowering the capital and operating costs associated with biofuel use. As well, the focus is on technical advances in the control systems, combustion chamber design, heat exchanger design, and modular or prepackaged systems.

## 4.6 FEDERAL PROJECT REFERENCES


4.1 "Fuel Peat Harvesting" (CREDA), Noval Technologies Ltd., St. John's, Nfld.

4.2 "Wet-Cell Wood Burner Using Wood Waste for Firing a Pulp Mill Lime Kiln", Lamb-Cargate Industries Ltd., Vancouver, B.C., 1978-79.

4.3 "Wood Residues as Fuel Source for Lime Kilns", Pulp and Paper Research Institute of Canada, Pointe Claire, Que., 1980-81.

4.4 "Wood Firing of Lime Kilns in Bleached Kraft Mills", Domtar Inc., Senneville, Que., 1983-84.

4.5 "Suspension Firing of Wood Wastes in a 250,000 lb./hr. Hog Fuel Boiler", H.A. Simons (International) Ltd., Vancouver, B.C., 1984-85.

4.6 "Test Program on Boilers Burning Wood Refuse", Canadian Boiler Society, Toronto, Ont., Envirocon Eastern Ltd., Mississauga, Ont., 1981-82.

4.7 "Boiler Test Program", SNC Inc., Montreal, Que., 1984-85.

4.8 "Feasibility of a Wood-Fueled Boiler System at Great Lakes Forest Research Centre", Sandwell & Co. Ltd., Vancouver, B.C., 1978-79.

4.9 "Wood Waste Fuels Preparation and Handling", B.H. Levelton & Associates Ltd., Vancouver, B.C., 1979-80.

4.10 "Evaluation of Wood Waste Energy Conversion Systems", B.H. Levelton & Associates Ltd., Vancouver, B.C., 1980-81.

4.11 "A Review of the Options Available to the Forest Industry for Producing Electricity from Wood Residues", B.H. Levelton & Associates Ltd., Vancouver, B.C., 1981-82.

4.12 "Comparative Assessment of Forest Biomass to Energy Conversion Processes", Simons Resource Consultants, Vancouver, B.C., and B.H. Levelton & Associates Ltd., Vancouver, B.C. 1981-82.

# CHAPTER 5

# CONVERSION TO LIQUID FUELS

# CHAPTER 5

# CONVERSION TO LIQUID FUELS

## 5.1 INTRODUCTION

THE DISCOVERY of significant oil reserves in Canada led to a sudden and dramatic reduction in the use of solid biomass and coal for energy applications. The conversion from solid to liquid fuels was accelerated by the latter's inherently superior fuel characteristics, including high energy density, good transportability and favourable combustion properties.

The convenience and ready availability of petroleum fuels and the extensive infrastructure of the liquid fuels industry are vivid testimony to their success in the marketplace. However, the potential for petroleum supply disruptions and, to a lesser degree, the unpredictable fluctuation of crude oil prices have created an atmosphere of uncertainty. This has prompted the development of production mechanisms and facilities to convert raw biomass to liquid fuels that have properties similar to petrofuels and that can be used in existing combustion systems.

Federal initiatives in the conversion of solid biomass to liquid fuels fall into three main groups: direct conversion of biomass to liquids via thermochemical liquefaction processes; indirect conversion, in which biomass is either gasified to a synthetic gas, which is subsequently reformed to alcohols, or is hydrolyzed to sugars for biological fermentation to alcohols; and extraction of plant and animal-derived oils.

## 5.2 DIRECT CONVERSION

The term liquefaction covers a number of technologies for the direct thermochemical conversion of lignocellulosic feedstocks to crude liquid fuels. Although most liquefaction processes also yield noncondensible gases and a char residue, the major product is normally an organic liquid that can be upgraded to produce fuel oils and/or chemicals.

There are two main liquefaction processes -- pyrolysis and solvolysis. This delineation is not without overlap, but there are several general characteristics that distinguish the two. Pyrolytic liquefaction involves the thermally-induced decomposition of biomass feedstock. Typically, these processes are low pressure, employ high temperatures (400°C to 500°C), and use relatively dry, coarse particulate feedstocks. Solvolytic liquefaction involves both thermal and solvent-substrate interactions. These high pressure processes employ lower temperatures (250°C to 350°C) and usually use a fine particulate feedstock slurried in a solvent carrier, often water.

Liquefaction of biomass involves a series of structural modifications and chemical reactions, including physical breakdown and depolymerization as well as secondary rearrangement reactions, the most important of which is deoxygenation. In some processes, catalysts and/or reducing gas atmospheres are used to promote these secondary reactions and hence achieve at least partial integral upgrading of the primary depolymerization products.

### 5.2.1 Pyrolytic Liquefaction

---

#### 5.2.1 (a) Traditional Slow Pyrolysis

Technically, slow pyrolysis is not a liquefaction process since the major product is a solid char and the liquid component rarely exceeds 25 percent. It is, however, the basic thermochemical process from which pyrolytic liquefaction has evolved.

The production of charcoal from solid wood blocks using simple kilns is a centuries-old process involving a combination of partial combustion and pyrolysis. True pyrolysis systems (often termed destructive distillation systems) were developed to manufacture high quality charcoal for steel production. A major industry developed in which large quantities of wood were pyrolyzed in indirectly heated steel retorts. The condensible liquid byproduct was collected and separated to yield a variety of tars, oils and chemicals for industrial use.

However, with the advent of petroleum-based chemicals and the use of coal-derived coke in steelmaking, the wood pyrolysis industry in North America virtually disappeared. In Brazil, where the steel industry still depends on charcoal, pyrolytic liquids from charcoal kilns continue to be collected and transported to steel mills for use as fuel.

In the energy crisis of the 1970s, traditional pyrolysis was reconsidered for the production of liquid fuels. In the United States, mobile and stationary pilot plants were

tested. Typically, the noncondensible gaseous product was burned to supply energy for the process. Plug-flow retorts, rotating drum kilns, and conveyor pyrolyzers were evaluated for operation on a variety of wood and agricultural materials. Although the process itself was technically feasible, the oil products were difficult to use because of their high viscosity and corrosive tendencies. In addition, the low yields of liquid fuel necessitated a high value market for the charcoal.

Pyrosol

In Canada, Pyrosol of Calgary, Alberta, conducted in-house tests on a commercial prototype conveyor pyrolysis unit using municipal solid waste (MSW) and other biomass feedstocks, but commercial implementation of the system was not achieved. As well, the University of Sherbrooke conducted several laboratory trials on the slow pyrolysis of agricultural residues, but the technology was abandoned in favour of vacuum pyrolysis [project ref. 5.1].

University of Sherbrooke

Wastewater Technology Centre

A research program on slow pyrolysis is currently under way at Environment Canada's Wastewater Technology Centre. Sewage sludge from several locations has been successfully converted to liquid and char products using a modified process based on a technique initially developed in Austria. Oil yields of up to 25 percent have been achieved in a small batch reactor and a continuous reactor with a 2.5 kg/h capacity is being developed.

5.2.1 (b) Vacuum Pyrolysis

In pyrolytic processes, the reaction zone residence time of the primary organic vapours is critical to the occurrence of secondary reactions that affect the yield ratios of solid, liquid and gaseous products. The University of Sherbrooke, working on the thermochemical conversion of peat, designed a vacuum reactor that removed evolved vapours in less than one second. The result was a significant increase in organic liquid yields.

University of Sherbrooke

With federal funding from ENFOR and Agriculture Canada, research on this small batch reactor was extended to include biomass materials such as wood, straw and corn stover [project ref. 5.2]. Moderate heating rates of approximately 10°C per minute, a vacuum of about 2 to 10 kPa, and final reactor temperatures of 530°C to 930°C produced organic liquid yields of 30 to 50 percent, while catalyzed tests on wood gave liquid yields of 55 to 60 percent.

Based on these encouraging results, funding was continued under the Bioenergy Development Program to design, construct and operate a 3 kg/h continuous vacuum pyrolysis unit [project ref. 5.3]. An electrically-heated, six-hearth reactor permits individual control of hearth temperatures and allows independent collection and condensation of the vapours evolving from each of the hearths. Feed hopper and char

container capacities are sufficient for three-hour runs on small chip feedstocks.

Optimization of the vacuum pyrolysis process is continuing and trials have been conducted on a wide range of materials. High yields of a light oil were obtained from shredded automobile tires and it is expected that a one tonne per hour industrial pilot plant will be constructed to further develop this application.

5.2.1 (c) Fast Pyrolysis

In contrast to traditional pyrolytic processes which employ slow heating rates and long residence times, fast pyrolysis involves the rapid heating of small particles for relatively short residence times followed by the immediate quenching of the pyrolytic products. These conditions reduce the yield of solid char and, when carried out at moderate temperatures, favour the production of organic liquids over the production of noncondensible gases.

University of Waterloo

A variety of fast pyrolysis systems are under development, but Canada's main effort is centred on a fluidized-bed reactor operated by the University of Waterloo. Federal funding under the ENFOR program initiated the development of a bench scale (15 g/h) atmospheric pressure flash pyrolysis unit based on a blow-through, fluidized-bed reactor [project ref. 5.4].

In this type of reactor, the particle size of the inert sand bed and the fluidizing velocity of the heated recycle gas are critical in achieving a system in which the bed material is retained in the reactor and the fine char particles are blown out of the bed, thus preventing any char build-up.

Finely ground biomass particles are injected into the fluid bed by a unique feed system and are rapidly heated by contact with the hot sand. Following a residence time of less than half a second, the pyrolytic products are swept from the reactor to a cyclone for char collection. Heavy and light liquid fractions are collected in hot and cold condensers. At the same time, the noncondensible gases are filtered to remove tar mists and are passed into a compressor. A portion of these gases is reheated and recycled to the reactor for use as the fluidizing medium.

Tests on this bench-scale system have been very encouraging. Organic liquid yields of 40 to 60 percent were achieved on agricultural residues such as straw, corn stover and bagasse, while yields of 60 to 70 percent were realized on hardwoods such as aspen and maple. At optimum temperatures of 500°C to 550°C, char yields ranged from eight to 10 percent and noncondensible gas yields were approximately 10 to 12 percent.

With additional federal support, the design was scaled up and a process development unit with a continuous operating capacity of 2 to 3 kg/h was constructed [project ref. 5.5]. Results have confirmed the high liquid yields obtained in the small-scale unit. The single-phase dark fluid contains 15 to 30 percent water, can be poured easily, and is relatively stable if not exposed to air. Using both pressure and air-atomizing nozzles as the feed mechanisms, the fluid has been successfully combusted in a simple chamber domestic oil burner.

University of Western Ontario

Another fast pyrolysis process, ultrapyrolysis, has been developed at the University of Western Ontario in London, Ontario. The technique, originally funded to optimize the yields of petrochemical intermediates and fuel gases, promises to produce high yields of organic liquids at moderate reaction temperatures (550°C to 650°C) and short residence times (less than 100 milliseconds). This project is discussed in greater detail in Chapter 6, Conversion to Gaseous Fuels, and Chapter 7, Conversion to Chemical Feedstocks.

### 5.2.2 Solvolytic Liquefaction

In Canada, substantial federal funding has been allocated to the research, development and economic evaluation of solvolytic liquefaction processes. These processes cover several loosely related technologies, including supercritical fluid extraction, hydroliquefaction (catalytic or noncatalytic), and organosolv liquefaction.

#### 5.2.2 (a) Supercritical Fluid Extraction

A variety of supercritical fluids (liquids or gases that are held above their critical temperatures by means of high pressures) can be used to remove organic liquid fractions from essentially nonvolatile raw biomass materials. A two-step approach, requiring an extraction vessel and a recovery facility, is normally used.

In the initial step, which is carried out under high pressure and temperatures, the biomass feedstock in dissolved in the supercritical fluid. The product is then precipitated out by reducing the pressure, raising the temperature, or both. The extraction solvent is then recompressed and recycled and the raw oil separated for upgrading.

B.C. Research

B.C. Research has investigated both batch and continuous laboratory-scale equipment using acetone and methanol as solvents [project ref. 5.6]. Researchers obtained oil yields of 40 to 70 percent from wood, while yields from peat were in the 40 to 50 percent range. Laboratory tests at the University of Laval gave oil yields of 25 to 60 percent when

using supercritical extraction with solvents such as pentane, benzene and tetrahydrofuran [project ref. 5.7].

5.2.2 (b) Hydroliquefaction

Hydrolytic liquefaction processes use an aqueous medium, often employ catalysts, and may utilize a reducing gas atmosphere. Typically, reaction temperatures are 300°C to 350°C, pressures are high, and yields of raw proto-oil range from 30 to 40 percent. These oils are dark, highly viscous, generally corrosive, and tend to polymerize in storage.

University of Toronto

University of Quebec

McGill University

Canadian activity in hydroliquefaction has focused on laboratory studies involving batch autoclave reactors. As well, semi-continuous bench scale systems have been constructed. Fundamental studies on the use of nickel-based catalysts and hydrogen have been conducted at the University of Toronto, while the University of Quebec has investigated the use of sodium formate and silica-alumina catalysts [project refs. 5.8, 5.9]. In addition, McGill University has studies a low-pressure, low-temperature approach using hydroiodic acid solvolysis [project ref. 5.10].

University of Saskatchewan

With federal support under the Bioenergy Development Program, (BDP) the University of Saskatchewan has constructed a 2 to 3 kg/h continuous extrusion reactor [project ref. 5.11]. Wood meal is hopper-fed to a screw feeder which forms a plug to resist reactor pressure. The feedstock is preheated and delivered to the tubular auger reactor. Ports in the reactor are used to inject a sodium carbonate catalyst, steam, and carbon monoxide reducing gas. An auger rotating at 7 rpm moves materials through the 42 cm long reactor. The temperature is maintained at about 360°C and the pressure at about 15 MPa.

University of Toronto

Under another recent BDP study, a new noncatalytic approach to hydroliquefaction, called rapid aqueous pyrolysis, has been developed at the University of Toronto [project ref. 5.12]. Small wood sticks immersed in water in sealed tubes are heated to 350°C within three to 10 minutes. Oil yields of 45 to 55 percent have been achieved and the proportion of phenols is high.

5.2.2 (c) Organosolv Liquefaction

A number of liquefaction processes are based on the use of an organic solvent carrier such as anthracene, phenolic hydrocarbons, creosote oil and recycled proto-oil. The solvent-substrate interaction is critical to the dissolution of the biomass feedstock as well as to its subsequent depolymerization and deoxygenation to organic liquids.

University of Sherbrooke

The major Canadian effort in this area is taking place at the University of Sherbrooke where a 12 kg/h semi-continuous process development unit is being operated using a two-stage approach [project ref. 5.13].

In the initial stage, ground biomass is slurried with an organic solvent, preheated to between 160°C and 230°C, and rapidly circulated through a high pressure differential shear valve. When structural breakdown and partial solubilization of the biomass takes place, additional feedstock is added to achieve a slurry concentration of up to 30 percent.

In the final stage, liquefaction takes place under pressures of 6 to 10 MPa in a tubular reactor maintained at about 325°C. When hydrogen reducing gas is added and residence times of five minutes are used, proto-oil yields of 60 to 70 percent have been demonstrated.

### 5.2.3 Proto-Oil Characterization and Upgrading

In the early stages of liquefaction research in Canada, there was little uniformity between research groups carrying out oil analyses and specifications. Consequently, it was impossible to compare the various liquefaction techniques being evaluated. Recognizing this, the Federal Government funded several major efforts to develop standard characterization techniques for biomass-derived oils.

U. of Sherbrooke & Waterloo

Programs at the University of Sherbrooke and the University of Waterloo specifically addressed the separation, identification and characterization of bio-oils and their chemical constituents [project refs. 5.14, 5.15]. These efforts, together with analytical work conducted by the Universities of Laval and Toronto, laid the groundwork for a centralized analysis of liquefaction products.

B.C. Research

Sponsored under the Bioenergy Development Program, the analysis will be conducted by B.C. Research at their facilities in Vancouver [project ref. 5.16]. Samples of biomass-derived liquids produced by members of the Canadian Biomass Liquefaction Community (CBLC) will undergo elemental analysis and will be tested for moisture and ash content. As well, the density, distillation curves and calorific values of the samples will be determined. Materials will be fractionated into broad chemical classes via sequential solvent chromatography and then characterized using a series of complicated analytic tests. Results will be made available to CBLC groups via the COSY computer system.

In addition to fostering study into oil characterization, the Federal Government has also provided funds to the Universities of Laval, Toronto and Waterloo to examine the catalytic upgrading of primary liquids [project refs. 5.15,

5.17, 5.18]. Laboratory reactors using either hydro-refining catalysts or H-ZSM5 preparations have successfully converted oils into light hydrocarbons.

## 5.3 INDIRECT CONVERSION

In contrast to direct conversion, in which solid biomass is converted in a single stage (or several integral steps) to an organic liquid product, indirect conversion involves distinct stages. The biomass feedstock is first converted to an intermediate product, which is then subjected to a further conversion sequence to yield a liquid fuel.

There are two major indirect conversion processes: thermochemical conversion, in which the feedstock is gasified to a synthesis gas and then converted to methanol; and biological conversion, in which the biomass is broken down into its component sugars and those sugars are subsequently fermented to produce ethanol.

### 5.3.1 Thermochemical Conversion (Gasification/Synthesis)

In the past, methanol was produced from wood by destructive distillation. This practice was abandoned with the invention of catalytic processes for synthesizing methanol from syngas, a 2:1 molar ratio of hydrogen and carbon monoxide.

Today, methanol production is based on the catalytic steam reformation of natural gas (methane) into syngas. However, methanol can also be produced from any carbonaceous material, including coal, peat and biomass, if those materials are first gasified. In contrast to natural gas reforming, biomass gasification yields a crude gas product that must be further refined. The main steps in producing a suitable syngas include a reformation of the crude gas to crack the methane and other hydrocarbon products present in the raw gas, a catalytic shift conversion to increase the hydrogen to carbon monoxide ratio, and an acid gas removal process.

The syngas is then compressed to between 3 and 10 MPa and fed into the methanol synthesis reactor. The exothermic reaction that takes place is catalyzed by a variety of compounds based on elements such as copper, zinc, chromium and aluminum. The crude methanol is sent to a distillation train for separation of light ends and higher alcohols.

In the overall conversion sequence described above, those aspects concerning the conversion of syngas to methanol are considered commercially proven technology. Only the biomass gasification step requires developmental work.

As discussed in Chapter 6, Conversion to Gaseous Fuels, the production of a medium-energy gas from biomass can be accomplished by oxygen, steam, or pyrolytic gasification. Of these approaches, oxygen gasification is the most advanced and is currently being examined at the pilot-plant scale in several countries. As well, various reactor designs are being studied -- Canada's effort has been directed to the development of a fluidized-bed system. The success of federally funded projects with INCO, C-I-L and Omnifuel has led to the implementation of a methanol-from-wood demonstration project by BIOSYN.

BIOSYN

A general partnership originally formed between Nouveler and Canertech, BIOSYN has undertaken the first phase of a project to demonstrate the conversion of biomass and peat to a synthesis gas that could serve as the feedstock for a traditonal methanol synthesis process. With $15.6 million from their own funds and $6 million from the Bioenergy Development Program, BIOSYN has constructed a 10 tonne per hour oxygen-blown pressurized gasifier based on the Omnifuel fluidized-bed design. An 18-month research and development program is testing the effects of fuel moisture content, operating temperature, pressure and fuel ash composition.

### 5.3.2 Hydrolysis and Fermentation

The hydrolysis of lignocellulosic materials to fermentable sugars can be carried out by two methods: chemical (or acid) hydrolysis and enzymatic hydrolysis.

Acid Hydrolysis: Traditional acid hydrolysis techniques have been used for over 100 years and the technology has been demonstrated in several full-scale commercial plants around the world. Performance data is extensive and results may be determined with a high degree of certainty. Generally, however, the technology has not proved itself commercially viable. The U.S.S.R. is currently the only country operating large-scale acid hydrolysis plants, although their technology will soon be used in a new Brazilian installation.

W.L. Wardrop

In Canada, the major R,D&D effort in acid hydrolysis has been the development by W.L. Wardrop and Associates of the hydrofluoric acid approach. Theoretically, hydrofluoric hydrolysis should be one of the best ways in which to break down lignocellulosic residues because of the overall efficiency of the reaction and high recovery of sugars.

Forintek

Research carried out at the National Research Council of Canada (NRC) and Forintek confirmed that high concentrations of fermentable sugars could be obtained and laboratory-scale results were validated [project ref. 5.19]. Nevertheless, various process engineering problems have been encountered

and it is apparent that this work is still at the developmental stage.

St. Lawrence Reactors

A significant advance in process technology has been made by researchers at St. Lawrence Reactors who have developed a patented dilute acid process for the hydrolysis of carbohydrate feedstocks [project ref. 20]. A continuous plug flow reactor features indirect steam heating, a high solids content slurry, and short reaction times. With the support of the Bioenergy Development Program, St. Lawrence Reactors is investigating this system for use in the hydrolysis of lignocellulosics.

Enzymatic Hydrolysis: Work into enzymatic hydrolysis began in the late 1940s when researchers started investigating cellulose degradation by fungi in an attempt to address deterioration problems with cotton-based materials used by the U.S. armed forces. Only in the last ten years, however, has there been any serious attempt to develop a viable saccharification process.

Basically, enzymatic hydrolysis consists of six interdependent operations:

* pretreatment of the lignocellulosic material,
* fractionation of the pretreated material into cellulose, lignin and hemicellulose,
* production of the cellulose enzymes,
* saccharification of the pretreated cellulose,
* fermentation of the liberated sugar,
* recovery of the alcohol,
* treatment of waste streams.

Although the technology is relatively new and unproven, enzymatic hydrolysis offers greater potential for cost reduction than does acid hydrolysis. Before the technology can be scaled-up to pilot plant or commercial levels, however, its basic aspects must be characterized. Recent innovations in enzymatic hydrolysis include improvements in pretreatment, enzyme production and fermentation.

5.3.2 (a) Pretreatment and Fractionation

Various pretreatment options have been investigated for enhancing the fractionation of lignocellulosic residues into their cellulose, hemicellulose and lignin components. Some of the first pretreatments studied included irradiation, ball milling, and pulping. These methods were either too expensive or did not effectively ensure that the substrate could be readily hydrolyzed by cellulose enzymes.

Steam pretreatment of lignocellulosics is now the preferred method and Canada is a world leader in this area. Canadian experience ranges from fundamental research carried out at Forintek, the University of Toronto and the University of

Sherbrooke to the process engineering and pilot projects of companies such as Tigney, Stake Technology and Iotech.

Tigney

Tigney has built a large-scale pilot plant at the Alberta Research Council in Edmonton, although liquid fuels have not been targeted as the primary product. Stake Technology has built several pilot plants and several full-scale pretreatment plants which have been used to pretreat lignocellulosics for use as a ruminant feedstock supplement. Much of the bioconversion work sponsored by the Government of France uses an autohydrolysis reactor built by Stake.

Stake Technology

Iotech

Iotech has constructed a one tonne/day pilot plant in Ottawa to demonstrate the company's patented steam pretreatment process. This process has already been used successfully in a number of projects in the United States, where Iotech worked as a contractor to the U.S. Department of Energy. The Ottawa plant incorporates pretreatment, enzyme production/ hydrolysis, and eventual fermentation of the sugars to ethanol. As well, Iotech is involved in a cost-shared project with the Bioenergy Development Program and the Government of Manitoba to examine the economic feasibility of scaling up their pretreatment process at Mohawk Oil's Minnedosa, Manitoba, ethanol distillery [project ref. 5.21].

University of Toronto

Work at the University of Toronto has investigated a prehydrolysis process combining steam pretreatment and a sulpur dioxide catalyst. Tests were carried out on aspen, pine and several agricultural residues [project ref. 5.22].

The flexibility of steam pretreatment has been demonstrated on a range of hardwood and agricultural residues and its success is evident by the range of countries using Canadian developed equipment and processes -- Australia, New Zealand, Sweden, Austria, France and the United States. Future work will focus on the development of equipment to fractionate the pretreated wood into the various downstream processing routes.

University of Waterloo

While steam pretreatment is the established leader in the field, research work at the University of Waterloo has suggested that organosolv pretreatment of wood may be as effective in enhancing the fractionation and conversion of a variety of lignocellulosic residues [project ref. 5.23].

Econotech

However, recent work on organosolv pretreatment by Econotech Services Ltd. of New Westminster, B.C., has shown that high yields of hemicellulose may not be compatible with high pulp strength [project ref. 5.24].

University of British Columbia

Researchers at the University of British Columbia are involved in commercial-scale trials in Brazil using organosolv technology developed and patented in Canada. The organosolv treatment effectively liberates most of the sugars, while the buffering solvent restricts the breakdown

of the free sugars to degradation products. The success of this technology will depend on the results obtained at the Brazilian plant.

5.3.2 (b) Enzyme Production and Hydrolysis

Critics of enzymatic hydrolysis say that the reaction is slow, complex and relatively expensive. The enzyme production step alone costs almost as much as all the other process considerations combined. Over the last five years, however, Canadian research in this area has advanced rapidly and concern over enzyme cost has been replaced by considerations over what should be done with the hemicellulose and lignin streams. The cost of enzyme production has been dramatically reduced by screening and developing mutant strains that produce more enzyme in a shorter time. Various mutants have been shown to be active on a wide range of lignocellulosic substrates, while scale-up trials have indicated a substantial savings in production costs when the enzymes are produced in large volume.

Enzymatic hydrolysis offers other advantages as well. For example, its saccharification process occurs at relatively low temperatures (30°C to 50°C) and does not require pressure and corrosion resistant vessels. Also, the reaction is highly specific and the hemicellulose and cellulose polymers are completely hydrolyzed to their component sugars. Because the reaction conditions are not severe, the lignin byproduct is highly reactive and shows promise as a chemical feedstock.

Iotech
Forintek

The commercialization of enzymatic hydrolysis is being addressed at the pilot plant level by Iotech and at the process development level by Forintek [project ref. 5.25]. Further research will enhance the efficiency and economics of the process, but the enzyme production step is already well on its way to commercial viability and has attracted the interest of enzyme production companies such as NOVO and Gist-Brocades.

5.3.2 (c) Fermentation

Both Brazil and the United States possess thriving industries based on the production of ethanol from starch and sugar-based materials. The growth of these industries has been paralleled by advances in process engineering and fermentor designs based on traditional brewing experience.

Canadian research has taken a different approach, focusing instead on wood-derived sugars and their inherent problems. Unlike cellulose, which is solely composed of glucose units, wood contains a high proportion of hemicellulose -- approximately 33 percent. Hemicellulose contains mostly five-carbon (or pentose) sugars, such as xylose, as well as a relatively high concentration of uronic acids and acetic acid. Traditional yeasts used by the brewing and baking

industry are not able to convert most of these hemicellulose-derived sugars into ethanol.

National Research Council

In the last five years, however, various yeasts capable of converting pentose sugars to ethanol have been identified. Much of this work was carried out at the National Research Council of Canada laboratories in Ottawa. Some of these strains can produce ethanol at concentrations greater than five percent and can be grown on substrates such as hydrofluoric-hydrolyzed aspenwood.

Labatts

Recently, this work has been further developed by Labatts using their fermentation and genetic engineering expertise. Concurrently, work is under way at the University of Toronto with strains of Pichia and Candida that can convert both five- and six-carbon wood-derived sugars to relatively high concentrations of ethanol.

Another potential way to utilize the hemicellulose stream is to convert it to a liquid fuel other than ethanol. In the early 1900s, butanol was produced in numerous commercial plants around the world. Low petrochemical costs eventually rendered this process uneconomic. However, for countries with low feedstock costs, such as South Africa, the production of butanol from carbohydrates can still compete with oil-based products.

Forintek

Research carried out at Forintek indicates that the sugar component of wood can be converted to near theoretical yields of butanol, making it competitive with traditional sugar and molasses feedstocks [project ref. 5.26]. This work has not yet advanced to the pilot plant level in Canada as technical and economic analyses indicate that market acceptance would be a major problem.

A French consortium has recently completed a pilot plant which produces butanol from agricultural residues. The butanol may be used as a cosolvent in gasoline as part of the European Economic Community's plan to eliminate leaded petroleum. If the French effort proves commercially viable, Canadian research on wood-based residues could be readily scaled up.

Forintek / Purdue University

Research at Forintek and at Purdue University has shown that another product, 2,3-butanediol, can be prepared from wood-based sugars [project ref. 5.27]. The microorganism that produces butanediol is ideally suited to utilizing wood sugars as it can ferment all the cellulose and hemicellulose-derived sugars to high solvent concentrations. Fermentation broth concentrations of butanediol in excess of 10 percent have been obtained and several U.S. firms are now interested in making butanediol from starch-based products, such as corn.

Research indicates that any fermentation systems developed for use with starch or sugar-based feedstocks can be readily adapted for use with wood-derived sugars. The main problem is that many chemical hydrolysis and pretreatment methods produce sugar and lignin breakdown products that are toxic to the microorganisms responsible for fermentation. However, significant progress has been made in this area: either the formation of these inhibitors is prevented, or they are isolated in a separate stream.

Mohawk Oil

Although large-scale fermentation facilities have been established at the Alberta Research Council, Allelix, the University of Waterloo, Iotech, and Weston Bakeries, Mohawk Oil of Minnedosa, Manitoba, is the only truly commercial plant in Canada that produces liquid fuel from a renewable feedstock. Using starch or sugar-based feedstocks, the company is Canada's biggest supplier of fermentation-derived fuel alcohol. The alcohol is blended with gasoline and sold as a gasohol mix in certain parts of Manitoba. Iotech and Mohawk have proposed merging their operations and using wood-derived sugars as the feedstock.

## 5.4 EXTRACTION

In the search for direct petroleum substitutes, a vast array of biomass sources have been studied, including animal-derived fats, oil-bearing microbes and, in particular, plant oils and latex extractives. Plant oils are recovered directly, by mechanical pressing, or indirectly, via solvent extraction with hexane, acetone or alcohols.

In Canada, several federally funded projects have investigated the operation of diesel engines on plant oils and whole plant extracts. Oils may be mechanically pressed from species such as canola, rape and sunflowers, while plant extracts may be obtained from species such as milkweed and alfalfa [project refs. 5.28, 5.29, 5.30].

The high viscosity of most raw oils can pose wintertime flow and atomization problems leading to engine cylinder deposits, increased exhaust emissions and higher engine wear. Improved performance has been obtained with methyl and ethyl esters of these oils.

Although plant oils have been technically proven as a fuel extender, they cannot currently compete with diesel fuel in Canada. However, bio-oils are being considered in other countries -- sunflower oil in South Africa and tallow-derived oils in Australia, for example.

The catalytic cracking of plant-derived oils for the production of petrochemicals may show promise if the plant residues can be economically used for other purposes.

## 5.5 SUMMARY

There are two inherent problems in using biomass as a fuel in Canada. Firstly, considerable distances separate Canada's vast biomass resource from market centres and, secondly, an extensive and efficient infrastructure based on liquid petrofuels is already in place. Thus, enhanced handling and transportability are two compelling reasons to produce an economically viable liquid fuel from biomass.

Direct conversion technologies, both pyrolytic and solvolytic, have taken great technical strides, and valuable information on the thermochemical breakdown and conversion of biomass to liquid products has been gained. In the near-term, the production of chemical byproducts may be more economically viable than the production of liquid fuel itself. However, further federal R,D&D efforts will bring these technologies still closer to commercial application. Already, the gasification and synthesis of methanol from biomass is technically proven and well on the way to being demonstrated at the industrial pilot plant level.

The fermentation of sugar and starch-based feedstocks to produce ethanol is being carried out on a commercial basis in countries such as the United States and Brazil, but lacks sufficient economic incentive for large-scale use in Canada. The thrust of Canada's work into liquid biofuels has centred on the process of enzyme hydrolysis and is still at the research and development level. Nevertheless, several Canadian companies have been very successful in exporting their technology to other countries, including Europe, Scandinavia, the United States and New Zealand. Given a more favourable economic climate, the production of liquid fuel from lignocellulosics could be rapidly scaled up.

## 5.6 FEDERAL PROJECT REFERENCES


5.1 "Pyrolysis of Agricultural biomass as a source of Fuels for Canadian Farm Operations", Sandwell Beak Research Group and University of Sherbrooke, Sherbrooke, Que., 1979-80.

5.2 "Detailed Design, Construction and Initial Operation of a Vacuum Pyrolysis Process Development Unit", University of Sherbrooke, Sherbrooke, Que., 1982-83.

5.3 "Vacuum Pyrolysis of Lignocellulosics", University of Sherbrooke, Sherbrooke, Que., 1984-85.

5.4 "Flash Pyrolysis of Wood Waste in a Fluidized Bed", University of Waterloo, Waterloo, Ont., 1979-80.

5.5 "Continuous Flash Pyrolysis of Wood", University of Waterloo, Waterloo, Ont., 1981-84.

5.6 "Supercritical Gas Extraction of Chemicals from Forest Products", B.C. Research, Vancouver, B.C., 1979-80.

5.7 "Supercritical Pyrolysis of Wood", NSERC study, University of Laval, Quebec, Que., 1981-82.

5.8 "Further Development of Processes for the Conversion of Wood to Liquid Fuels and Chemicals Through the Operation of a Continuous-Semicontinuous Liquefaction Unit", University of Toronto, Toronto, Ont. 1982-83.

5.9 "Direct Catalytic Liquefaction of Biomass", University of Quebec, Varennes, Que., and Sandwell Beak Research Group, Toronto, Ont., 1982-83.

5.10 "Low Pressure-Low Temperature Process for the Conversion of Wood to Liquid Fuels and Chemicals", McGill University, Montreal, Que., 1983-85.

5.11 "Study of Continuous Screw Reactor Liquefaction", University of Saskatchewan, Saskatoon, Sask., 1984-85.

5.12 "Wood Liquefaction in a Cascade Autoclave System", University of Toronto, Toronto, Ont., 1984-85.

5.13 "Liquefaction Studies", University of Sherbrooke, Sherbrooke, Que., 1984-85.

5.14 "Development of a Method for Characterizing Pyrolytic Oils", University of Sherbrooke, Sherbrooke, Que., 1981-82.

5.15 "Characterization of Pyrolysis Oils from Continuous Flash Pyrolysis", University of Waterloo, Waterloo, Ont., 1981-84.

5.16 "Conduct the Centralized Analysis for the Biomass Liquefaction Project", B.C. Research, Vancouver, B.C., 1984-85.

5.17 "Production of Oils from Wood" (NRCC), University of Laval, Quebec, Que., 1981-84.

5.18 "The Upgrading and Utilization of Synthetic Crude Oil Produced by Wood Liquefaction", University of Toronto, Toronto, Ont., 1983-84.

5.19 "Conversion of Cellulose to Ethanol Using a Two-Stage Process", Forintek Canada Corp., Ottawa, Ont., 1981-85.

5.20 "Conversion of Lignocellulosics to Ethanol", St. Lawrench Reactors, Mississauga, Ont., 1986-87.

5.21 "Scale-up Testing of Iotech's Enzyme Production Process Using Chemical Grade Feedstock and the RL -P37 Organism", Iotech Corp. Ltd., Ottawa, Ont., 1983-84.

5.22 "Hydrolysis of Lignocellulosics by Sulphur Dioxide", University of Toronto, Toronto, Ont., 1983-84.

5.23 "Pretreatment Preparation of Forest Biomass as Feedstock for Bioconversion Processes", University of Waterloo, Waterloo, Ont., 1981-82.

5.24 "Use of Organosolv Processes", Econotech Services Ltd., New Westminster, B.C., 1984-85.

5.25 "Conversion of Cellulose to Ethanol Using a Two-Stage Process", Forintek Canada Corp., Ottawa, Ont., 1981-82.

5.26 "Liquid fuel Production from Hemicellulose", Forintek Canada Corp., Ottawa, Ont., 1981-82.

5.27 "Production of Liquid Fuels from Lignocellulosic Residues Using an Integrated Combined Enzymatic Hydrolysis and Fermentation Approach", Forintek Canada Corp., Ottawa, Ont., 1984-85.

5.28 "Whole Plant Oils -- A Potential Renewable Fuels Extender" (ENERSEARCH/ERDAF), Saskatchewan Research Council, Saskatoon, Sask., and Forintek Canada Corp., Ottawa, Ont., 1982-84.

5.29 "Conversion of Rapeseed Oil to Esters for Use as Diesel Fuel" (Agriculture Canada), University of Guelph, Guelph, Ont., 1982-83.

5.30 "Canola Oil as Fuel for Farm Diesel Engines" (Agriculture Canada), University of Saskatchewan, Saskatoon, Sask., 1982-83.

# CHAPTER 6

# CONVERSION TO GASEOUS FUELS

# CHAPTER 6

# CONVERSION TO GASEOUS FUELS

## 6.1 INTRODUCTION

A MAJOR FOCAL point in the development of bioenergy technologies is the conversion of solid biomass feedstocks to gaseous fuels. Convenient and easy to handle, biomass-derived gases contain varying proportions of inert gases (nitrogen and carbon dioxide) and combustibles (hydrogen, carbon monoxide and methane, as well as other hydrocarbons).

Compared to solid biomass, gaseous biofuels are extremely versatile. They can be burned to produce heat for thermal applications or used to generate steam, electricity or shaft power. As well, existing gas- and oil-burning systems can be easily retrofitted to accommodate their use. Gaseous biofuels offer other benefits as well:

* Ease of transportation: Local distribution by pipe networks is simple, clean and inexpensive. Several separate burners throughout a plant or industrial complex can be served by a central gas production unit.

* Control precision: Gaseous fuels are combusted in stable, relatively simple burners that are readily automated and can be precisely metered. These burners offer excellent turndown ratios.

* Efficiency: Excellent fuel/air mixing produces a high thermal efficiency.

* Low emissions: Since gaseous fuels are generally low in particulate matter, pollution control systems are usually not required.

Federal research into biomass-derived gaseous fuels has centred on two major areas: thermochemical and biological conversion. Thermochemical systems employ high-temperature thermal energy to break down the complex biomass structure into simple components and are usually used to process solid or concentrated liquid feedstocks. Federal projects have reconfirmed the economic and technical viability of traditional processes such as fixed-bed air gasification, as well as investigated new areas such as fluidized-bed technologies.

Federal and private sector efforts in biological gasification have established the environmental and energy benefits of anaerobic digestion. These systems employ microorganisms that break down biomass at low or moderate temperatures to produce "biogas". They are normally used to treat relatively dilute organic slurries, although on-site production of methane from municipal solid waste in landfills is a notable exception. Compared to thermochemical processes, biological conversion reactions are relatively slow.

## 6.2 THERMOCHEMICAL GASIFICATION

The thermochemical breakdown of biomass involves a complex series of irreversible physical and chemical changes that are initiated by the application of heat energy. There are three basic thermochemical processes: pyrolysis, gasification and combustion. The use of these terms varies slightly both in the scientific literature and within the bioenergy community. For the purposes of this review, the following definitions will apply:

Pyrolysis is the initial and primary stage in the thermal breakdown of biomass. Pyrolysis processes involve a moderate-temperature reaction that yields solid, liquid and gaseous products. The net endothermic reaction occurs in response to an externally supplied heat source. No air or oxygen is added: therefore, any oxygen present in the products originates from the feedstock itself. Typically, the production of condensible organic liquids and/or carbonaceous char is maximized, while the production of noncondensible gases is limited.

Gasification takes the thermochemical process a step further. It includes a primary breakdown by pyrolysis plus additional reactions involving the initial pyrolytic products. In these high temperature reactions, the principal product is a combustible, noncondensible gaseous fuel. The production of condensible organic liquids and residual char is minimized.

The heat driving gasification reactions can be supplied from an external source or, more commonly, is generated within the reactor by the combustion of a portion of the fuel. Twenty-five to 50 percent of the oxygen required for complete combustion is supplied from an outside source.

Combustion includes the initial pyrolysis and gasification reactions plus the complete oxidation of the liquid, gaseous and char products. The final product of the high-temperature reactions is a noncombustible, noncondensible gas with no organic liquids or solid residue. Complete oxidation in an excess of air ensures maximum release of thermal energy.

Combustion and pyrolysis processes have already been covered in Chapters 4, Direct Combustion, and 5, Conversion to Liquid Fuels. This discussion deals only with gasification and is limited to processes intended to maximize the production of combustible, noncondensible gaseous products.

### 6.2.1 Low-Energy Gaseous Fuels

Low-energy gaseous (LEG) fuels are produced by the process of air gasification. The heat energy required to drive the reaction is generated within the reactor by an external air flow that supplies only enough oxygen to combust a portion of the feedstock. Nitrogen-rich air introduced into the reactor dilutes the product gases, resulting in a typical heating value of less than 10 megajoules per Normal cubic metre (MJ/Nm3).

This low-energy gas is a mixture of combustible and noncombustible gases, as follows:

| | |
|---|---|
| Carbon monoxide | 17 - 20% |
| Hydrogen | 16 - 20% |
| Methane | 2 - 3% |
| Hydrocarbon gases | 0.2 - 0.4% |
| Nitrogen | 45 - 50% |
| Carbon dioxide | 10 - 15% |

In addition, the product gas contains a good deal of water vapour and often a small percentage of a complex mixture of condensible organic liquids, carbon particles and inorganic ash.

The economics of LEG are best when the gas is used immediately in closely coupled applications. LEG can be used to displace fossil fuels by retrofitting boilers, kilns, dryers, ovens and space heaters. It is also the preferred fuel for applications requiring a clean burning flame, such as ceramic ovens and brick kilns. In addition, the gas can be cleaned and cooled for use in internal combustion engines, both for stationary applications (such as water pumping and the generation of electricity) and for mobile vehicles (including trucks, tractors and boats).

Canadian researchers have developed a variety of reactor configurations for air-blown gasifiers. Classified by the type of fuel bed employed, these include fixed-bed, stirred-bed, fluidized-bed and entrained-flow gasifiers.

#### 6.2.1 (a) Fixed-bed Gasifiers

In fixed-bed systems, plugs of the raw biomass fuel are usually gravity-fed through the gasifier. The reactor contains specific, defined temperature gradients and fixed

reaction zones for drying, pyrolysis, combustion and reduction stages.

Fixed-bed systems can be further classified according to the direction of the gas flow relative to the fuel flow, as follows: countercurrent (updraft), co-current (normally downdraft, but occasionally updraft), and cross-draft. Several new fixed-bed designs incorporate a combination of updraft, downdraft and cross-draft components.

Updraft Gasifiers: Simple, stationary updraft gasifiers have been used since the 1850s. Often, these old gasifiers featured massive brick and masonry construction. A proven technology, they are still used today in certain applications.

Due to their ability to use low quality fuels, updraft gasifiers are often installed at logging and pulp mills to process forest residues. To achieve maximum combustion efficiency for the high tar/oil content gas they produce, the systems are usually set up as close-coupled retrofits to boilers, kilns and dryers.

Updraft systems can also be designed to operate internal combustion engines, principally for the generation of electricity. However, extensive filtering is required to remove the condensible tar/oil portion of the gas and the overall efficiency (13 to 15 percent) is low.

Updraft gasifiers exhibit the following characteristics:

* they can handle wet fuels of up to 30 to 50 percent moisture content,

* they can tolerate a relatively high ash or fines content,

* the gas produced has a high carbon monoxide to hydrogen ratio,

* the off-gas is relatively cool and has a high tar and condensible aqueous content, but is usually low in particulates.

Solid biofuels are fed from the top of the reactor and move slowly downward through drying, pyrolysis, reduction and combustion zones. Air is distributed to the bottom of the fuel bed, which rests on a fixed water- or air-cooled grate. The direction of gas flow is upward, counter to the fuel flow, and producer gas is withdrawn from the top of the reactor. Ash normally falls through the grate and is removed from the base of the gasifier.

Typical problems include ash clinkering and grate overheating from excessive combustion zone temperatures, channeling in the fuel bed, and tar condensation in the upper reactor, off-gas liner and burners.

Several North American firms currently supply commercial updraft systems. Some of these offer standard warranties and performance guarantees based on successful industrial operating experience of five years or more. The development of these systems has, for the most part, taken place in the private sector, though the Federal Government has had some involvement in this area.

ADI Ltd.

In one federal project, ADI Ltd. of Fredericton, N.B., monitored a commercial gasifier prototype manufactured by a U.S. firm, Forest Fuels Inc. [project ref. 6.1]. Installed as a retrofit to a small hot water boiler at the Sleepy Hollow Correctional Centre near Charlottetown, P.E.I., the unit was designed to use boiler flue gases to predry whole tree chips. The monitoring program revealed a poor performance level due to inappropriate fuel quality, inadequate fuel drying, poorly designed handling equipment and low energy demands. The system was eventually dismantled.

Westwood Polygas

In another federal project, Westwood Polygas tested and monitored two 1.4 tonne/hour commercial updraft gasifiers designed by Moore Canada [project ref. 6.2]. Installed at Ainsworth Lumber in Chasm, B.C., the prototype reactors were fueled by wood chips and mill residues containing 35 to 50 percent moisture. The gasification system was was designed to supply a cool, scrubbed low-energy gas to fire lumber-drying kilns.

Testing, monitoring and modification of one of the gasifiers was was carried out over several years: however, operation was discontinued following a severe economic downturn in 1982.

Downdraft Gasifiers: Petroleum fuel shortages during World War II focused attention on the development of vehicle-mounted mobile gasifiers. The requirement for a gaseous fuel that was light in weight and low in tar content led to the rapid development of downdraft gasifiers.

In this type of gasifier, plugs of fuel introduced into the top of the reactor move downward due to gravity. As in updraft gasifiers, ash is removed from below the grate at the bottom of the reactor. Unlike updraft systems, however, the combustion air is injected through tuyeres, or openings, located around the edge of the fuel bed just above a constriction, or throat, in the lower part of the reactor above the grate.

This establishes a combustion zone in the tuyere area and a char reduction zone between the throat and the grate. Since the output gas is withdrawn from below the grate, all gases produced in the upper reactor must pass downward, co-current to the fuel flow, through the high-temperature combustion and reduction zones. This causes thermal cracking of the tar/oil

component of the gas, converting it to a noncondensible form. Thus, the output gas in downdraft gasifiers has a very low condensible hydrocarbon content, typically one-tenth that of updraft gasifiers.

Downdraft gasifiers are characterized by:

* the production of a gas with a relatively low tar/oil content, a low carbon-monoxide-to-hydrogen ratio (approximately 1.2 as opposed to 2.0 for updraft gasifiers), and a high hydrogen content, the principal contaminants being ash and char particulate,

* an inability to operate effectively on high-moisture fuels (feedstock moisture content is typically below 20 percent),

* a requirement for fuel of a relatively large particle size (large chips or preferably small blocks) with a minimal fines content,

* a limitation to relatively small reactor sizes, usually less than 10 gigajoules per hour (GJ/h) or roughly 1.6 metres in diameter.

Problems with downdraft gasifiers almost always relate to fuel quality: bridging of the fuel bed in the upper reactor from oversize or stringy fuel components, slagging from high fuel ash or inorganic contaminants, reduced output and bed plugging from high fuel fines content, and poor quality gas from excessive fuel moisture.

In countries without an indigenous supply of petroleum fuels, such as Brazil, downdraft gasifiers have been widely installed for stationary applications, including boiler retrofits, kilns and dryers. In North America, however, the inability of downdraft systems to operate on wet particulate feedstocks, such as sawdust or hog fuel, has severely limited their economic potential.

Provided that stringent fuel specifications are met, traditional downdraft gasifiers are considered proven technology. Turnkey systems are available worldwide from dozen of suppliers and hundreds of systems have already been installed.

In Canada, research, development and demonstration programs on downdraft gasifiers were initiated in the mid 1970s. In addition to several trials on vehicle-mounted gasifiers and small-scale laboratory tests, major demonstration programs were conducted by Saskatchewan Power Corporation and Forintek. These efforts were complemented by modelling studies at Queen's University in Kingston, Ontario, and commercial installations in Prince Edward Island and the Northwest Territories.

Queen's University

Previous to government involvement, gasifier testing and development had been proceeding on a trial and error basis without fundamental data on the mechanisms involved in biomass gasification. Therefore, federal funds were made available to Queen's University to develop mechanical and empirical models of downdraft gasifier operation and to generate a computer simulation package for use in gasifier design and operation optimization [project refs. 6.3, 6.4].

Forintek

Some of the data used in the Queen's study was obtained through another federal project conducted by Forintek's Eastern Forest Products Laboratory [project ref. 6.5]. In an intensive test program involving a downdraft gasifier system purchased from a manufacturer in California, Forintek examined the unit's operation on a variety of fuels including wood chips, sawdust and bark mixtures, densified wood pellets, and hogged whole tree mini-rotation hybrid poplar. Fuel quality and operating data were then related to gas yield and composition.

Sask. Power Corp.

Saskatchewan Power Corp. also contributed to the Queen's University modelling work. Under a federal test program, data was collected to relate fuel moisture content, particle size, air injection rate, temperature, and ash removal rate to producer gas temperature, composition, heating value and production rate [project ref. 6.6].

In 1980, Saskatchewan Power imported an IMBERT fixed-bed downdraft gasification system from Germany. The unit was laboratory tested at the utility's Regina research facility and field tested at a remote fishing camp at Jan Lake [project ref. 6.7]. The batch-fed gasifier operated on air-dried wood chips and the low-energy gas produced was cleaned and cooled to fuel an internal combustion engine connected to a 60 kW generator.

P.E.I. Energy Corp.

With federal assistance, two commercial downdraft gasifiers were also installed. One of these, a 0.5 tonne/hour DUVANT system erected by P.E.I. Energy Corp. in Hurry Road, P.E.I., provided gas to a retrofitted oil boiler to heat greenhouses at a government forest nursery [project ref. 6.8]. Continuous operation of the installation was not achieved for two reasons: the chip fuel available proved unsuitable, and problems were encountered with grate overheating and excessive tar condensation in the gas transfer fan.

Techwest Enterprises

The second installation, an IMBERT gasification system, was installed by Techwest Enterprises in the small community of Fort Providence, N.W.T. [project ref. 6.9]. Including a downdraft gasifier, gas cleaning and cooling modules, and a 120 kW engine-generator set, the unit has achieved continuous operation burning chips from fire-killed pine. Initial problems with engine stall were caused by air leakage into the gasifier during fuel charging.

Dual-Flow Gasifiers (Updraft/Downdraft): A variation of downdraft gasification involves a dual cycle with elements of both updraft and downdraft operation. In this type of gasifier, known as the De Lacotte design, the upper section of the reactor operates in an updraft mode with gas flow countercurrent to the downward fuel flow. Water vapour from the drying zone and pyrolytic gases from the char production (pyrolysis) zone are drawn off the top of the reactor by an air-blast venturi. The mixed air/pyrolysis gases are then combusted in an external high-temperature refractory-lined chamber and the hot combustion products returned to the central section of the main gasifier reactor.

Some of these gases move upward to provide heat for fuel pyrolysis and drying, while the greater proportion flows downward co-current to the char movement in the reduction zone. The product gas and ash are taken off at the base of the reactor as in a simple downdraft gasifier.

Since the pyrolytic vapours are cracked in the external combustor, a clean, tar-free gas is produced. Another advantage of this gasifier configuration is the accommodation of a higher fuel moisture content. This capability is due to the updraft mode's more effective heat transfer to the incoming fuel.

The dual-flow gasifier, available from several European manufacturers, has never been installed in Canada. However, its general principle of operation is being used in the Heuristic stirred-bed gasifier described below.

Cross-Draft Gasifiers: As in other fixed-bed designs, cross-draft gasifiers are characterized by a gravity-induced, downward flow of fuel. The direction of gas flow, however, is across the fuel flow. Air is injected in one side of the lower reactor, forming a localized combustion zone, and producer gas is extracted from the opposite side after passing through the reduction zone. In the past, this type of gasifier was produced primarily for use on vehicles and was operated on charcoal or coke. In Canada there has been little interest in cross-draft gasifiers, although this flow design is being used in the second stage of the Heuristic stirred-bed gasifier.

6.2.1 (b) Stirred-Bed Gasifiers

There are several gasifier designs that can not be classified as fixed-bed since they rely on mechanical movement of the bed. These systems may use screw auger reactors, rotary kilns, mechanically agitated vertical retorts, or paddle-stirred, multiple-chamber units. In general, the mechanical movement of the bed allows for the use of finer fuels, such as sawdust or hog fuel, and often serves to physically separate the drying/pyrolysis and gasification/combustion

zones. This separation facilitates thermal cracking of the tar/oil pyrolysis products and yields a high quality, relatively clean gas.

Heuristic Engineering

In 1982, the B.C. Science Council provided funds for the initial construction of a Canadian-designed, vertically-stacked, two-stage gasifier. An initial updraft stage accommodates fuel drying and pyrolysis, while the char produced is mechanically transferred to a lower second stage for cross-draft gasification. Designed for an output of 3.2 GJ/h, the microprocessor-controlled system is expected to achieve successful operation on high moisture hog fuel. The continued development and testing of this configuration is now being funded under EMR's Bioenergy Development Program [project ref. 6.10].

6.2.1 (c) Fluidized-Bed Gasifiers

Unlike fixed-bed gasifiers, which were widely used prior to the petroleum era, fluidized-bed systems are a modern technology developed largely by the petrochemical industry.

Typically, fluidized-bed reactors use an inert granular bed, such as hot silica sand or a bed of ash and char particles, that is expanded and suspended by a rapid upward flow of air injected through a distributor that forms the base of the reactor.

The biomass feedstock is mechanically injected into the bed and is quickly distributed by the intense bubbling and mixing action. Rapid heating from contact with the hot sand causes the biomass particles to dry, pyrolyze and gasify as they circulate. This creates a relatively uniform temperature throughout the bed, unlike fixed-bed gasifiers in which reaction zones are well defined and stationary.

The output gases separate in a disengaging zone above the bed and are piped to hot cyclones for the recycling of large char particles and the collection of ash and fines.

Fluidized-bed systems offer the following advantages over traditional fixed-bed gasifiers:

* a wide range of particle sizes, from fines to large chunks, can be accommodated,

* a uniform, relatively low bed temperature prevents slagging and allows the use of high ash or dirty fuels,

* high moisture feedstocks (up to 55 percent) can be utilized, although for effective operation feedstocks should be dried to less than 30 percent moisture content,

* air and fuel feed can be independently adjusted for precise automated control of bed temperature and gas quality,

* fluidized beds are simple to scale up and are well suited to large installations.

Fluidized-bed systems have certain drawbacks as well:

* high auxiliary power requirements for pressurizing the fluidizing air,

* a complex, automated control system which makes small-scale units uneconomic,

* a limited turn-down ability since fluidization must be maintained,

* a relatively high entrainment of particulates in the product gas due to the highly agitated bed,

* a product gas which can have a moderate condensible organic vapour content due to the incomplete cracking of the pyrolytic tars.

The potential of fluidized-bed gasification of biomass was recognized early by the Canadian bioenergy community and strong federal support has been provided for both fundamental laboratory research and for industrial development to the pilot plant and commercial prototype stages. Major Canadian initiatives, carried out by Eco-Research, Omnifuel Gasification Systems, and BIOSYN have served as cornerstones in establishing fluidized-bed gasification as a commercially viable bioenergy technology.

Eco-Research

In 1976, Eco-Research, a subsidiary of Canadian Industries Ltd. (C-I-L), constructed a pilot plant in Kingston, Ontario, to produce a refuse-derived fuel (RDF) from mixed municipal and commercial wastes. The system included a one tonne per hour fluidized-bed gasifier for conversion of the RDF to a low-energy fuel gas.

Under a 1979 federal contract, the unit was tested for its ability to gasify wood chips and forest industry mill residues [project ref. 6.11]. Continuous one-month runs established the feasibility of using an air-blown fluidized-bed reactor to produce a good quality, low-energy gas. The success of the trials led several of the project engineers to form a new company, Omnifuel Gasification Systems, to design and market commercial gasifiers.

Omnifuel Gasification

One of Omnifuel's first projects was a 110 t/d gasifier, purchased with federal and provincial assistance by a forest industry complex in Hearst, Ontario, for operation on mixed wet and dry mill residues. The world's largest fluidized-bed biomass gasifier, the unit commenced operation in 1981, supplying low-energy gas via pipeline to several hot oil boilers for process and space heating purposes.

With additional federal/provincial funding, Omnifuel carried out an intensive 15-month monitoring and demonstration program on the Hearst system [project ref. 6.12]. The gasifier module performed well over 8,000 hours of operation without signs of refractory or structural weaknesses and, when supplied with appropriate fuel, it met or exceeded design specifications. The gasifier operated successfully on fuel moisture contents ranging from five to 42 percent and with fuel feed rates of two to 10 tonnes per hour.

The economic recession in the forest products industry prevented the continued operation of the Hearst gasifier; however, the project was instrumental in establishing large-scale fluidized-bed gasification as a technically viable option for retrofitting existing petro-fueled systems. It also paved the way for commercial installations in the United States.

BIOSYN

Based on Omnifuel's developmental work, BIOSYN (a general partnership owned by Nouveler Inc. of Montreal, Quebec) constructed a pressurized, fluidized-bed reactor for the oxygen gasification of biomass to produce a syngas for methanol synthesis. (This project is described in detail in Chapter 5, Conversion to Liquid Fuels.)

BIODEV

BIODEV International was formed by the SNC Group of Montreal and Nouveler to commercially exploit this technology in the air-blown configuration. A gas cleaning and cooling system was designed and installed and the pressurized low-energy gas fed to an 800 kW dual-fuel diesel engine from ALSTHOM Atlantic of France.

Based on this work, Electricite de France has ordered a 6.7 MW mini-grid electrical generation system for installation in French Guyana. It is anticipated that a significant export market exists for these systems and BIODEV, in association with ALSTHOM, is offering turnkey systems in the one to 17 MW range.

### 6.2.1 (d) Entrained-Flow Gasifiers

In entrained-flow gasification systems, small feedstock particles are injected into a flow of high temperature gases and are pyrolyzed/gasified as they are carried in suspension through the reactor. Extensive research and development has been carried out on 150 to 900 t/d coal-operated systems, but only limited efforts have been undertaken for biomass feedstocks.

Ontario Research Foundation

The Ontario Research Foundation conducted a brief trial on entrained-flow gasifiers under a 1979 federal contract [project ref. 6.13]. Dry, powdered wood was injected into the natural gas/oxygen flame of a jet burner designed for iron

ore roasting. Data on the fundamentals of entrained-flow gasification was acquired, but the equipment proved unsatisfactory and work was not continued.

Regatech

In Toronto, a commercial entrained-flow biomass gasifier is being developed by Regatech. Particulate feedstocks of less than 15 percent moisture content are fed into a two-stage reactor for high-temperature flash pyrolysis and char gasification. Based on several years' testing of a small prototype in the U.S., the company is now constructing a 10 GJ/h commercial prototype.

### 6.2.2 Medium-Energy Gaseous Fuels

Medium-energy gas (MEG) has a heating value of 10 to 20 MJ/Nm3 and generally consists of hydrogen, carbon monoxide, methane, small amounts of hydrocarbon gases and carbon dioxide. It is produced by means of oxygen, steam or pyrolytic gasification of biomass and, like low-energy gas, can be used as a fuel for use in retrofit thermal applications and internal combustion engines.

As long as it is not diluted with nitrogen, MEG has sufficient energy density to warrant short-term storage or transport over moderate distances. Of particular interest is its potential as a synthesis gas that can be used as the feedstock for production of liquid fuels, such as methanol and gasoline, and chemicals, such as ammonia.

#### 6.2.2 (a) Oxygen Gasification

Oxygen-blown gasifiers operate on the same principle as air gasifiers, but since there is no nitrogen entering the reactor, the gaseous products are not diluted and a much greater reactor throughput is possible. Several types of fixed-bed oxygen gasifiers have been tested, but the greatest development has occurred in oxygen-blown, fluidized-bed systems. Such systems are operating in pilot plants in several countries.

Early federal funding of research and development in fluidized-bed oxygen gasification has placed Canadian technology at the forefront of world expertise in this area.

Inco Metals

In a major project under the ENFOR program, Inco Metals demonstrated the feasibility of fluidized-bed gasification of wood using oxygen and subsequently designed a 100 t/d prototype wood gasification plant [project ref. 6.14].

The two-year project, conducted at Inco's research facility in Toronto, involved the design, assembly and operation of a 20 cm diameter reactor with an alumina sand bed, fluidized by

a flow of oxygen and steam. Hammermilled wood chips were screw-fed directly into the fluid bed at a rate of 115 kg/h.

Continuous runs of up to three and a half days were carried out with an optimum bed temperature of 850°C to 900°C and an oxygen/wood ratio of 0.2 to 0.3. A medium-energy gas of 15 MJ/m3 was produced with a net efficiency of about 64 percent. The typical gas composition was as follows:

| | | | |
|---|---|---|---|
| Carbon monoxide | - 48% | Hydrocarbons | - 3% |
| Hydrogen | - 18% | Nitrogen | - 2% |
| Carbon dioxide | - 15% | Oxygen | - less than 1% |
| Methane | - 13% | | |

This unit, one of the world's first fluidized-bed oxygen gasifiers to be operated on biomass, provided extensive fundamental data that was basic to the development of several U.S. and European gasification programs.

Eco-Research / Omnifuel

Eco-Research's one tonne per hour pilot plant and Omnifuel's 110 t/d commercial unit, previously described under air gasification, were not designed for the production of medium-energy gas. However, the scale-up data, limited experience using oxygen at atmospheric pressure, construction detail, and general operating experience gained with these systems provided invaluable information in the development of a Canadian expertise in fluidized-bed gasification of biomass and led to construction of BIOSYN's commercial-scale pressurized fluidized-bed reactor for the demonstration of syngas production.

BIOSYN

Based on an investment of $15.6 million from BIOSYN and $6 million from EMR, construction began in 1983 on a 10 t/h gasifier to operate on forest residues and peat. Located at St-Juste-de-Bretenieres, Quebec, the gasifier is designed to operate at 1.7 to 2.0 MPa and 850°C on predried, shredded biomass fuel.

Under an 18-month research and development program, BIOSYN will test for fuel moisture content, operating temperature, pressure and fuel ash composition [ref. 6.15]. Tests will also determine energy and mass balances, carbon conversion, oxygen requirements and environmental implications. A feasibility study for methanol synthesis and a mathematical model for the gasification process will be carried out.

### 6.2.2 (b) Steam Gasification

In air and oxygen gasification, a portion of the fuel is combusted within the reactor to provide the thermal energy needed to drive the endothermic pyrolysis/gasification reactions. In steam gasification, combustion does not occur within the reactor and heat must be supplied from an external source. Typically, this is accomplished by the movement of hot solids to the gasifier from an external combustor, by

conduction through the reactor walls, or by in-bed heat tubes. Superheated steam introduced to the reactor supplies some of the required heat energy and participates in the complex chemical reactions involved in char gasification.

Battelle Columbus

Although no significant steam gasification program has been undertaken in Canada, major research and development projects have been carried out in the U.S. involving steam-fluidized, inert-bed reactors. A 12 t/d process development unit operated by Battelle Columbus features a steam-blown, high-throughput, fluidized-bed gasifier with a hot sand transfer system involving a separate fluidized-bed char combustor. A 6 t/d steam fluidized-bed gasifier at the University of Missouri-Rolla receives its heat supply from fuel gas combustion in in-bed firetubes.

University of Missouri-Rolla

6.2.2 (c) Pyrolytic Gasification

The process of pyrolytic gasification gives high yields of medium-energy gas. Thermal breakdown of the feedstock is achieved by the transfer of externally generated heat without the addition of oxygen, air or steam. Gas yields in excess of 80 percent and heating values of 13 to 19 MJ/Nm3 can be obtained with little or no char residue.

A unique feature of these systems is their very high heating rates, usually achieved by direct contact of the biomass particles with high temperature heat transfer surfaces. They are also characterized by high reaction temperatures, short residence times and rapid quenching of the product gases to prevent secondary reactions. Various catalysts can be employed to influence the composition of the gaseous product.

Laboratory-scale research and development into pyrolytic gasification is being pursued in several countries. In Canada, there have been two federally-funded projects in this area.

SNC Group / Rockwell

In a project sponsored by the National Research Council (NRC), The SNC Group and Rockwell International examined the pyrolytic/catalytic gasification of wood in molten salt baths [project ref. 6.16].

A hybrid poplar particulate feedstock with a 50 percent moisture content was introduced into an electrically-heated molten bath of sodium carbonate. At reaction temperatures of 850°C to 1,000°C, a medium-energy gas with a heating value of 13 MJ/Nm3 was produced. The gas had a hydrogen content of 42 percent, a carbon monoxide content of 24 percent and a methane content of 10 percent. Although the process is technically feasible on a commercial scale, it cannot compete on an economic basis with low-cost fossil fuels.

University of Western Ontario

The second project, conducted by the University of Western Ontario, was initiated under ENFOR and has been continued under NRC and EMR sponsorship. The project involves a novel pyrolytic gasification process for the production of a medium-energy gas from dry particulate biomass feedstocks [project ref. 6.17]. The laboratory-scale, continuous-operation pilot plant utilizes a vortical reactor to achieve turbulent mixing of the biomass particles with a high-temperature solid or inert gas heat carrier. A variable diameter entrained-flow reactor provides controlled, short residence times with rapid product quenching through contact with a cold, inert particulate stream in a second vortical reactor.

The system operates under heating rates of 10,000°C to 100,000°C per second in a temperature range of 650°C to 900°C and at residence times of between 50 and 900 milliseconds. At 900°C and residence times greater than 100 ms, a 90 percent conversion to noncondensible gases is realized. Only traces of residual char are produced. Approximately 20 percent of the feedstock is converted to hydrocarbons. While the production of such a fuel gas is not commercially viable, the process is being considered for production of high value chemical intermediates.

University of Western Ontario

Other federal projects have focused on the pyrolytic gasification of biomass via high intensity electrical energy. A brief laboratory test at the University of Western Ontario explored the use of high voltage electrical discharges on wood samples as a means to achieve the rapid heating rates and high temperatures required for pyrolytic gasification [project ref. 6.18]. Although a medium-energy gas of 10 MJ/Nm3 with a significant acetylene content was produced, the mass conversion was low and no practical commercial process was evident.

Resorption Canada / PPRIC

In another federal project, pilot plant tests on plasma arc gasification of wood chips were carried out by Resorption Canada [project ref. 6.19], while a technical and economic assessment of the results was performed by the Pulp and Paper Research Institute of Canada [project ref. 6.20]. Researchers expected that the very high temperatures generated by the plasma arc torch would achieve high conversion ratios of biomass to medium-energy gases. In fact, nitrogen dilution arising from the air flow used to control the torch resulted in a low-energy gas of about 8 to 9 MJ/Nm3. Therefore, even discounting the cost of the electricity consumed, the economic potential for this technology is low.

### 6.2.3 High-Energy Gaseous Fuels

A high-energy gas (HEG) of 25 to 30 MJ/Nm3 (similar to natural gas) can be obtained by the hydrogasification of biomass. Fine particulate feedstocks are pyrolytically gasified to produce a gas composed of methane and small quantities of higher hydrocarbon gases. The fact that the reaction takes place in a hydrogen atmosphere contributes to high methane yields. Laboratory processes currently being investigated are characterized by rapid heating rates, short residence times and rapid product quenching, in addition to the use of high pressures and catalysts.

Considerable work has been conducted on hydrogasification. Most studies have taken place in the U.S. and Europe, but there have been two Canadian-sponsored projects -- one at the University of Toronto and the other at the University of Waterloo.

University of Toronto

Under the ENFOR program, the University of Toronto conducted a series of tests using a laboratory flash pyrolysis reactor previously used in hydrogasification studies on coal and oil sands [project ref. 6.21]. A high-intensity electrical heater was employed to pyrolyze small samples of wood flour under a high pressure flow of hydrogen. Initial non-catalyzed tests examined the effects of heating rate (25°C to 800°C per second), pressure (450 to 1,400 psi) and peak temperatures (520°C to 1,200°C). In general, methane yields were increased by faster heating rates, higher reactor temperatures and greater hydrogen pressures.

In the study's second phase, researchers examined the effects of several catalyst systems on the hydrogasification of wood. With nickel-based catalysts, rapid heating rates, and high hydrogen pressures, a carbon-to-methane conversion of over 60 percent was achieved.

University of Waterloo

In a recent Bioenergy Development Program project, the catalytic hydrogasification of biomass was further investigated using the University of Waterloo's fluidized-bed reactor system [project ref. 6.22]. Researchers used a nickel on alumina hydrogenation catalyst, a reactor temperature of 550°C and a residence time of about 0.4 seconds. Under a hydrogen/nitrogen atmosphere, a 67 percent carbon-to-methane conversion was achieved. The product gas had a heating value of almost 30 MJ/Nm3.

Preliminary economic analysis suggests that a commercial hydrogasification system might be of interest to countries without indigenous sources of high-energy gaseous fuels. In Canada, however, the abundant supply of low-cost natural gas reduces the likelihood of this technology's short-term commercial development.

## 6.3 BIOLOGICAL GASIFICATION

The production of high quality methane fuel gas by the anaerobic digestion of biomass is a promising technology, especially in light of the environmental benefits associated with the biological treatment of agricultural and industrial wastes.

Without these environmental credits and the promise of valuable byproducts, anaerobic digestion would not be economically viable in today's industrialized nations. In lesser developed countries, such as China and India, however, biogas production for energy purposes alone has already been implemented. The equipment used in these countries is relatively simple, but appropriate to the nature of the indigenous feedstocks and the level of local expertise.

Past Canadian research and development efforts in anaerobic digestion have been largely directed by the National Research Council (NRC), Agriculture Canada, and Environment Canada's Wastewater Treatment Centre. Fundamental research has also been conducted at the University of Waterloo, University of Regina, and University of British Columbia. Federal activity in biological gasification is now coordinated by EMR's Bioenergy Development Program.

NRC

In cooperation with Agriculture Canada and several private Canadian companies, NRC has developed a downflow stationary fixed-film (DSFF) reactor which is now being tested in several scale-up demonstrations. Operating conditions and reactor configurations have been optimized for various biomass feedstocks, including animal manure, food processing residues and agricultural wastes.

Canviro Consultants

The DSFF concept has been integrated into several commercial prototypes, including those being developed by Canviro Consultants Ltd., MacLaren Engineers Inc., and Centre de Recherche Industrielle du Quebec (CRIQ). Canviro Consultants Ltd. has successfully incorporated a protein recovery system into their anaerobic digestion process [project ref. 6.23]. Commercial exploitation of the protein market is vital to the economic viability of their system.

Wastewater Technology Centre / ADI Ltd.

Other biogasification efforts, such as those of the Wastewater Technology Centre (Environment Canada) and ADI Ltd. have been concerned primarily with waste treatment rather than energy production [project ref. 6.24]. Currently, more than ten advanced biogasification systems are under construction or already operational in Canada. Large-scale investment, however, has been limited by the low price of conventional petrofuels.

## 6.4 SUMMARY

The Federal Government has devoted considerable research, development and demonstration effort to the conversion of biomass to gaseous fuels. Projects have covered a wide range of biomass feedstocks and have examined many potential applications, including the retrofit of existing thermal systems, the fueling of internal combustion engines, and the generation of electricity.

In biological conversion, the old technology of anaerobic digestion has been tested, improved and established as technically and economically viable for its dual role in environmental control and byproduct energy generation. Innovative Canadian systems are being successfully marketed in foreign countries where effective effluent treatment processes are required.

In thermochemical conversion, progress has been varied. The old technology of fixed-bed air gasification, developed under conditions of premium fuel scarcity, has been tested and reconfirmed as viable. These gasifiers are simple, inexpensive and effective in converting oil- or gas-fired systems.

Currently, most commercial systems for converting biomass to gaseous fuels are close-coupled. This means that the energy user is still faced with the high costs and difficulties involved in preparing, handling and storing intractable solid biomass fuels.

The new thermochemical technology of fluidized-bed air gasification has been developed and demonstrated and is now being implemented. When conversion to biomass fuels can be justified as economic, gasification offers a technically sound alternative to direct combustion.

Continued research and development efforts are being devoted to the production of medium-energy and high-energy gaseous fuels via oxygen, steam, and pyrolytic gasification, as well as hydrogasification. In the long term, breakthroughs in these technologies could eventually lead to the centralized pipeline transport of biomass-derived gaseous fuels.

## 6.5 FEDERAL PROJECT REFERENCES

6.1 "Monitoring of the Wood Gasifier at Sleepy Hollow Correctional Centre, Charlottetown, P.E.I." (DREE federal-provincial agreement), ADI Ltd., Fredericton, N.B., 1979-80.

6.2 "The Development of the Ainsworth Lumber Company Wood Waste Gasifier" (ENFOR/CANMET), Westwood Polygas Ltd., Vancouver, B.C., 1978-80.

6.3 "Technical Basis for Assessing Gasifier Design and Operation, Queen's University, Kingston, Ont., 1979-80.

6.4 "Technical Assessment of Downdraft Wood Gasifiers", Queen's University, Kingston, Ont., 1981-82.

6.5 "Evaluation of Fuels for Operation of a Fixed-Bed Downdraft Commercial Gasifier", Forintek Canada Corp., Ottawa, Ont., 1979-81.

6.6 "Evaluation of a Wood Gasifier: Environmental and Social Impact Study on Utilization of Wood for Small-Scale Electric Power Generation", Saskatchewan Power Corp., Regina, Sask., 1979-80.

6.7 "Pilot Plan Investigation of a Wood Gasifier for Generation of Electricity", Saskatchewan Power Corp., Regina, Sask., 1979-80.

6.8 "Installation of a Duvant Gasifier in P.E.I." (DREE), P.E.I. Energy Corp., Charlottetown, P.E.I., 1980-82.

6.9 "Downdraft Gasifier Testing: Fort Providence, N.W.T.", Techwest Enterprises, Vancouver, B.C., 1982-83.

6.10 "Development of a Heuristic Engineering Gasifier to Convert Wet Hog Fuel to Produce Gas", Heuristic Engineering Inc., Vancouver, B.C., 1984-85.

6.11 "Application of a Fluidized Bed to the Conversion of Forest Biomass into Energy", Eco-Research Ltd., Willowdale, Ont., 1979-80.

6.12 "Final Report on Gasifier Monitoring Program", Omnifuel Gasification Systems, Toronto, Ont., 1980-82.

6.13 "Alternative Methods for the Rapid Gasification of Wood", Ontario Research Foundation, Mississauga, Ont. 1978-79.

6.14 "Application of Fluid Bed Technology to the Gasification of Waste Wood", Inco Metals Co., Toronto, Ont., 1978-79.

6.15 "The BIOSYN Project", BIOSYN, Montreal, Que., 1983-86.

6.16 "Molten Salt Technology for Wood to Syngas Conversion" (NRCC), The SNC Group, Montreal, Que., 1982-85.

6.17 "High Intensity Pyrolysis of Wood and Biomass to Produce Ethylene, Reactive Chemical Intermediates, and Synthesis Gas of Low Coke Makes", University of Western Ontario, London, Ont., 1980-81.

6.18 "Electrical discharge Flash Pyrolysis of Biomass", University of Western Ontario, London, Ont., 1982-83.

6.19 "Economic Evaluation of the Gas Yields from a Plasma Pyrolysis-Gasification System Using Wood-Based Fuels", Resorption Canada Ltd., Ottawa, Ont., 1982-83.

6.20 "Economic Feasibility of Wood Gasification Using a Plasma Pyrolysis Reactor", Pulp and Paper Research Institute of Canada, Pointe Claire, Que., 1982-83.

6.21 "Rapid Devolatilization/Hydrogenation of Biomass Material, Phase I and II", University of Toronto, Toronto, Ont., 1979-81.

6.22 "Catalytic Hydrogasification of Wood", University of Waterloo, Waterloo, Ont., 1984-85.

6.23 "Evaluation and Optimization of Protein Recovery from Anaerobically Fermented Beef Cattle Feedlot Wastes", Canviro Consultants Ltd., Kitchener, Ont., 1981-85.

6.24 "Feasibility Assessment of Biogas Generation by Anaerobic Fermentation of Pulp and Paper Wastes", ADI Ltd., Fredericton, N.B., 1982-83.

# CHAPTER 7

# CONVERSION TO CHEMICAL FEEDSTOCKS

# CHAPTER 7

# CONVERSION TO CHEMICAL FEEDSTOCKS

## 7.1 INTRODUCTION

HISTORICALLY, the derivation of chemical products from biomass has been a very important industry, one traditionally independent of energy considerations. The production of biomass-derived bulk commodity chemicals, for example, including cellulose-derived plastics, acetic acid, alcohols, furfural, glycerol, turpentine and phenolics, has been and continues to be an important area of activity.

In the early part of this century, low-volume, high-value specialty chemicals were produced from a wide range of plant materials. Some of these chemical products included tannins, waxes and dyes, as well as numerous extracts used in pharmaceuticals, cosmetics, and food flavouring and preservation. With the advent of petrochemical, biochemical and synthetic sources, however, industrial production of specialty chemicals from biomass took a downturn.

Recently, federal government initiatives have stimulated renewed interest in the production of chemicals from biomass. These initiatives embrace two major objectives: the production of petrochemical fuel substitutes and the marketing of byproduct chemicals to improve the economic outlook for biofuel production systems. A major achievement has been the discovery of pyrolytic pathways and processes, with the result that previously unattainable yields of valuable specialty chemicals have been demonstrated.

### 7.1.1 Biomass Components

Lignocellulosic biomass, this country's principal bioenergy resource, has three major constituents: cellulose, hemicellulose and lignin. Collectively, these components represent dry matter proportions as low as 60 percent in straws and greater than 95 percent in woods. Individually, the proportion of each varies widely with species, maturity and individual plant component.

Minor constituents of biomass include inorganic ash and extractives. Ash content varies from a mere fraction of a percent in woods to greater than 30 percent in some straws. The extractive content of biomass also varies widely, from only a few percent in woods to levels of 20 to 25 percent in many herbaceous plant species.

## 7.2 TRADITIONAL CHEMICAL DERIVATIVES

### 7.2.1 Chemical Pulping

Throughout the world, chemical pulping is widely used as a means of fractionating wood and other biomass materials, including cotton, straw, bamboo, bagasse and tropical grasses. Typically, only a small proportion of the cellulosic fibre produced is used for the production of chemicals, but the dissolved hemicellulose and lignin byproducts represent a vast source of chemical feedstocks. In Canada, a significant number of byproduct chemicals can be produced in association with pulp production.

#### 7.2.1 (a) Cellulose Derivatives

The main structural element of plant cells, cellulose is a linear polymer of glucose (six-carbon sugar) units linked together laterally by hydrogen bonds to form elementary fibrils. These fibrils are joined to form microfibrils which, in turn, are joined to form cellulose fibres. Due to its strong covalent bonds, cellulose exhibits high tensile strength. It is insoluble in most solvents, including alcohol, ether, and alkaline solutions, but is easily hydrolyzed by acids.

The two main feedstocks used in the production of cellulosic derivatives are cotton linters and purified wood pulp. About four percent of Canadian chemical pulp is converted to rayon, cellulose acetate, and cellulose nitrate.

Cellulose nitrates are prepared by treating cellulosic materials with nitric acid, sulfuric acid and water. Used in the manufacture of plastics, lacquers, cements and explosives, cellulose nitrates exhibit water resistance, dimensional stability and durability.

Celluloid, the first commercially produced plastic, is manufactured by mixing cellulose nitrate with pigments and fillers in a solution of camphor and alcohol. Although still used in the manufacture of combs, brushes and pens, the use of celluloid has declined in recent years due to its high flammability.

Cellulose acetates are made by mixing and dissolving high quality pulp in solutions of acetic anhydride, acetic acid and catalyst. After treatment, the cellulose acetate is precipitated from the solution in the form of flakes which can be stored, transported or processed further. To produce filaments, the acetate flakes are redissolved in acetone and forced through fine nozzles to remove the solvent and form solid fibres.

Cellulose acetate is used in the manufacture of fabrics, such as Celanese, acetate and rayon, as well as plastics, lacquers, safety films, safety glass and insulating materials. Cellulose acetate materials are resistant to weathering, impact, light deterioration, and fungal and bacterial attack. Due to its high dimensional stability, cellulose acetate is used extensively in the plastics-moulding industry.

Cellulose xanthate is formed when cellulose is mercerized (treated with sodium hydroxide) and exposed to carbon disulfide gas. The resulting thick orange-coloured solution, known as viscose, is forced through small openings in an acid bath and hardened into rayon fibres. Similarly, the viscose can be pressed through narrow slits and into an acid bath to form cellophane sheets.

Cellulose ethers are formed by treating cellulose with sodium hydroxide and chemicals such as alkyl chlorides. Most cellulose ethers are water soluble and are used as additives in thickening agents, emulsifiers, paper coatings, and dimensional stabilizers.

7.2.1 (b) Lignin Derivatives

Lignin is a complex phenylpropane polymer characterized by a large number of methoxyl groups. It acts as the natural binding agent in plant cells. Lignin is commonly prepared by dissolving the polysaccharide portion of lignocellulosic materials with strong acids.

In the paper industry, the chemical pulping of wood generates vast quantities of lignin byproduct. In acid sulfite pulping, wood chips are cooked in an aqueous solution of bisulfite (usually calcium) in an excess of sulfurous acid. The liquid byproduct, known as spent sulfite liquor, contains a lignosulfonate residue which can be precipitated out using lime, resulting in yields of about 400 to 450 kg/tonne of pulp.

The lignin residue, which has a relatively high heating value, can be combusted directly as a fuel, added to mineral mixtures to improve adhesion properties, or used as a moulding compound for thermosetting plastics. As well, the lignosulfonate fraction can be further degraded to low-molecular-weight products. Of these, the most commercially

important is the flavouring, vanillin, obtained by the alkaline oxidation of softwood lignosulfonates. During sulfite pulping, degradation of the lignin results in the formation of small amounts of methanol.

In the sulfate (kraft) pulping process, the wood is cooked in a solution of sodium hydroxide and sodium sulfide. While most of the kraft black liquor waste stream is burned to generate process steam, the lignin fraction can be precipitated out with mild acid and purified by treatment with carbon dioxide. Similar to lignosulfonates, isolated kraft lignins can be used as dispersants, stabilizers or additives. With treatment, kraft lignin may be converted into a thermosetting phenolformaldehyde adhesive for panelboard manufacture. The lignin can also be broken down and treated to yield valuable low-molecular-weight products such as the solvent, dimethyl sulfoxide.

7.2.1 (c) Hemicellulose Derivatives

Hemicelluloses are slightly branched, low-molecular-weight polysaccharides that can be recovered with alkalis or hydrolyzed to simple sugars by acids. The principal hemicellulose in hardwoods is xylan: glucomannans are a minor constituent. In softwoods, galactoglucomannans predominate, while the main hemicellulose in cereal straws is arabinoxylan.

While the hemicellulose component of wood is automatically removed during pulping, its recovery and utilization is not widely practised. However, the potential for chemical extraction exists.

In sulfite pulping, the hemicellulose portion of wood is acid hydrolyzed to form simple sugars, such as galactose and mannose, which can be fermented to ethyl alcohol. Hardwood xylose, which is converted into furfural, escapes with the steam and can be recovered and used as a solvent or chemical intermediate. Acetic acid, produced in the breakdown of the hemicellulose, is more predominant in hardwood than in softwood pulping. In kraft pulping, the major hemicellulose products formed are acetic, formic, and hydroxy acids.

7.2.1 (d) Extractives

Extractives are nonstructural cell components that are soluble in water or organic solvents. Most important of the extractives are oils, resins, fatty acids, carbohydrates, tannins, waxes and various pigments.

Tall oil is an important byproduct formed during sulfate pulping of resinous woods. Since tall oil forms as a soap, it rises to the top of the kraft liquor where it can be skimmed off. Acidification of the soapy material yields crude tall oil. Some tall oils have a high concentration of sterols,

making them potential sources of Vitamin D. Crude tall oil can be further refined by fractional vacuum distillation to yield fatty and resin acids. The fatty acid fraction can be used in the production of soaps, while the resin acids, which crystallize and form sulfate rosins, are used as a substitute for gum or wood rosin.

The composition and quantity of crude tall oil obtained from kraft liquor depends on the tree species, length of storage, and pulping conditions used. Five to 40 kg of crude tall oil per tonne of pulp can be expected from most North American coniferous species.

Crude sulfate turpentine can be recovered from the condensates of digester relief gases. After dewatering, the crude turpentine is refined by distillation. Depending on the tree species, yields range from about five to 25 litres per tonne of pulp. Pine oil is produced as a distillation byproduct.

### 7.2.2 Destructive Distillation

The carbonization or pyrolysis of biomass materials (particularly wood) for the production of charcoal is an old technology. This thermal degradation process generates substantial quantities of pyroligneous acids, from which chemicals such as methanol, acetic acid and acetone can be obtained.

In the nineteenth century, destructive distillation of wood was practised primarily to recover these valuable chemicals. One dry tonne of hardwood yielded about 300 to 400 kg of charcoal, 40 to 45 kg of acetic acid, 25 to 30 litres of refined methanol, and 70 to 80 litres of wood tar and oils.

Charcoal production is still a large industry, but the availability of low-cost petroleum chemicals has made the recovery of bulk chemicals uneconomic. Limited thermal degradation of wood is still carried out for the recovery of liquid smoke used in food flavouring.

### 7.2.3 Extractive Processes

The recovery of biomass extractives is a small, but viable industry concerned principally with the production of low-volume, high-value chemical products. (This excludes the giant food processing industry which extracts oils from agricultural crops such as corn, sunflowers, peanuts, soya and canola.)

In the era of wooden shipbuilding, a large naval stores industry flourished to manufacture turpentine, rosin, pitch, tar, and pine oils for protecting surfaces and caulking seams of ships. Certain yellow pines were the preferred species since they contain relatively large quantities of oleoresin gums. Traditionally, gum turpentine and gum rosin were derived from oleoresins tapped from standing trees. Wood turpentine and wood rosin, on the other hand, were obtained through steam or solvent treatment of chipped wood. Although the old methods are still practised, most of the so-called naval stores chemicals are currently produced as byproducts of the kraft pulping industry.

Another extractives industry is based on the recovery of essential oils from the foliage and wood of several coniferous tree species -- notably red and white cedar, spruce and balsam fir. Fresh needles and small twigs are chopped, then steam distilled to yield a crude oil (0.2 to 1.0 percent dry weight basis). The raw oils are fractionated and refined to produce a variety of high-value scenting agents and chemicals used in pharmaceuticals, liqueurs, perfumes and cosmetics.

Extractives from woody or herbaceous plants are used in the manufacture of such diverse products as specialty waxes, emollients for skin care products, natural insecticides and optical adhesives.

## 7.3 BIOENERGY CHEMICALS

### 7.3.1 Thermochemical Processes

#### 7.3.1 (a) Supercritical Fluid Extraction

Canadian research, initiated under ENFOR and continued under the Bioenergy Development Program, is showing promise for the production of biomass-derived chemicals. In recent years, considerable work has been conducted on the supercritical fluid extraction of biomass to yield chemical feedstocks.

In this process, liquids or gases kept above their critical temperatures by means of high pressures are used to extract substances from essentially nonvolatile raw materials. Typically, a two-chamber process using an extraction vessel and a recovery facility is used. The first step is to dissolve the biomass in the supercritical fluid. The product is then precipitated by reducing the pressure, raising the temperature, or both. Finally, the extracting solvent is recompressed and recycled.

Since secondary reactions are inhibited by the blanket of fluid and rapid withdrawal from the reaction, relatively nonvolatile materials can be recovered with little or no decomposition. Also, since the diffusivity of supercritical fluids is much greater than that of regular liquids, the rate of extraction is enhanced. In fact, the energy associated with fluid compression can be less than the heat required for the evaporation and distillation stages of conventional liquid solvent extraction.

B.C. Research

At B.C. Research, supercritical fluid extraction research was carried out on batch and continuous laboratory-scale equipment using acetone and methanol [project refs. 7.1, 7.2, 7.3]. Oil yields from wood were 40 to 70 percent, while yields from peat reached 40 to 50 percent. Low-temperature extraction of peat with supercritical propane or carbon dioxide produced a clear wax in yields of over three percent.

University of Laval

As part of an investigation into the fundamental thermal decomposition of wood, laboratory tests at the University of Laval gave oil yields of 25 to 60 percent when using supercritical extraction solvents such as pentane, benzene and tetrahydro-furan [project ref. 7.4].

7.3.1 (b) Pyrolysis

The slow pyrolysis of wood was a flourishing industry in the nineteenth century and large quantities of chemicals, including methanol, acetic acid and acetone, were produced in addition to various tars and oils. With the advent of cheap petroleum, the recovery of chemicals from biomass by pyrolysis was no longer economic and commercial production came to an end. Subsequent work on the pyrolysis of biomass for fuels confirmed that chemical intermediates are produced during the thermal breakdown of wood, although secondary reactions cause coke formation and reduce chemical yields.

University of Western Ontario

A major ENFOR project at the University of Western Ontario in London, Ontario, involved the development of a novel ultrapyrolysis process for the production of ethylene and other hydrocarbons [project ref. 7.5]. The process features high heating rates, high reactor temperatures, controlled short residence time, and rapid product cooling to maximize yields of nonequilibrium chemical intermediates.

The university is currently operating a continuous laboratory-scale ultrapyrolysis pilot plant. Preheated inert solids and biomass particles are injected through separate ports into a high-temperature, turbulent vortical reactor. The products then pass through a variable-length, tubular entrained-flow reactor and are subsequently quenched by contact with a cold inert particle stream in a second vortical reactor.

At temperatures approaching 900°C, more than 90 percent of the cellulose feedstock is converted to gas. The remaining product fraction consists of light volatiles and no char is produced. About 20 percent of the cellulose is converted to hydrocarbon gases. Ethylene yields of greater than seven percent have been achieved.

University of Waterloo

U. of Sherbrooke

Two pyrolytic processes -- the University of Waterloo's flash pyrolysis system and the University of Sherbrooke's vacuum pyrolysis system (described in the liquid fuels chapter) -- were initiated with the intent of producing liquid fuels [project refs. 7.6, 7.7, 7.8, 7.9]. Now, they are being examined for their potential in producing specialty chemicals. The use of various biomass feedstocks, including peat, agricultural residues, and various components of industrial wastes, is being investigated.

7.3.1 (c) Catalytic Upgrading

Considerable federal research effort has been devoted to examining the potential for catalytic upgrading of the liquid and gaseous primary products of thermochemical conversion processes. Crude proto-oils from various biomass liquefaction techniques have been found to contain from eight to 24 percent oxygen, to have significant quantities of water, and to possess characteristics similar to the heavier heating oils. Catalytic upgrading greatly improves the ability of biomass liquefaction processes to compete in the premium fuel and chemical markets.

U. of Laval, Sask., and Waterloo

Current interest centres on the application of shape-selective zeolite catalysts in the ZSM-5 family that have the ability to deoxygenate a large number of compounds by dehydration and decarboxylation. The primary products of biomass pyrolysis are converted to hydrocarbons with a virtual absence of coke formation. Experimental work in this area has been carried out at the Universities of Laval, Saskatchewan, and Waterloo [project refs. 7.10, 7.11, 7.12].

7.3.1 (d) Byproduct Utilization

Many byproduct streams from traditional biomass processing have been assessed as potential feedstocks for the derivation of fuels or the direct production of energy.

In the sulfate pulping of resinous softwoods, for example, fatty and resin acids occurring in the wood are saponified by the pulping liquor. The soap is removed with the spent liquor and skimmed off following partial evaporation. The skimmings are then reacted with sulfuric acid to convert the sodium soaps into free fatty and resin acids. A gravity separator is used to produce crude tall oil that is about 70 percent fatty and resin acids and 30 percent unsaponifables.

Prince Albert Pulp

A federally supported research program carried out by Prince Albert Pulp on the utilization of tall oil in diesel engines concluded that although technically feasible, this application was not economically viable [project ref. 7.13]. The cost of upgrading the tall oil raised its cost to about that of diesel fuel. However, this work did lead to a highly successful application of tall oil in the potash and coal mining industries.

Two Canadian potash mines are already using tall oil in a 10/30 petroleum-based blend as a dust control agent. The mixture is applied to the potash before loading on rail cars. Similarly, a coal mining operation is using a tall oil mixture to control dust in its fluidized-bed coal drier. Ultimately, tall oil could totally replace the petroleum-based dust suppressants used by both these industries.

### 7.3.2 Biological Processes

#### 7.3.2 (a) Lignin Utilization

Mohawk Oil

Large-scale commercial operations such as the Mohawk Oil plant in Minnedosa, Manitoba, have already demonstrated the feasibility of utilizing starch or sugar-based materials as fermentation substrates for the production of fuel ethanol.

Biohol & Iotech

Smaller facilities, however, including Weston's Biohol plant, in Toronto, and Iotech Corp. Ltd.'s Ottawa facility, are trying to establish the technical and economic feasibility of producing ethanol from lignocellulosics such as wood, straw and peat.

These feedstocks contain a substantial proportion of lignin which cannot currently be converted to a fermentable substrate. Although the lignin can be burned for energy production, its use as a higher value chemical feedstock would significantly improve the overall economics of the process.

Forintek

With federal support, Forintek Canada Corp. has evaluated the use of byproduct lignin in adhesives for wood composite products [project ref. 7.14]. Tests showed that a lignin-based adhesive developed by Iotech worked effectively in waferboard, although the required pressing time was longer than for traditional composites using phenolic resins. It has been projected that two to three full-scale wood-to-ethanol plants would produce enough byproduct lignin to meet most of the North American demand for composite board adhesive.

Lignin obtained from steam-treated wood differs substantially from kraft lignin obtained as a pulping byproduct. Characterization studies carried out at Forintek have shown that lignin from steam-treated woods can be more readily fractionated into more uniform streams and that many of these

lignins are highly reactive [project ref. 7.15]. This high reactivity means that the different lignin fractions should be more easily modified to high volume markets, such as sulphonated lignins and resins. This work has advanced to the stage where kilogram quantities of lignin can be produced and characterized.

## 7.4 SUMMARY

With the current availability and low cost of petroleum fuels, possibilities for the economic production of liquid fuels from biomass appear limited. On the other hand, the high value of specialty chemicals provides incentive to continue investigating the potential for the non-energy utilization of biomass derivatives.

Federal support initiatives have significantly advanced the technologies involved in the biological and thermochemical breakdown of biomass. The knowledge gained has led to the realization that a harsh, one-step conversion of biomass to a simple petroleum substitute may be less desirable than the ordered, sequential fractionation of biomass into a range of traditional and energy-related fuels, chemicals and products.

## 7.5 FEDERAL PROJECT REFERENCES


7.1 "Supercritical Gas Extraction of Chemicals from Forest Products", B.C. Research, Vancouver, B.C., 1979-80.

7.2 "Biomass Feedstocks from Poplar Wood Using Supercritical Fluids", B.C. Research, Vancouver, B.C., 1982-83.

7.3 Sacrificial Agents for Enhanced Oil Recovery (EOR) from Peat", B.C. Research, Vancouver, B.C., 1984-85.

7.4 "Supercritical Pyrolysis of Wood", NSERC study, University of Laval, Quebec, Que., 1981-82.

7.5 "Ultrapyrolysis of Cellulose and Wood Components", University of Western Ontario, London, Ont., 1980-83.

7.6 "Flash Pyrolysis of Wood Waste in a Fluidized Bed", University of Waterloo, Waterloo, Ont., 1979-80.

7.7 "Continuous Flash Pyrolysis of Wood", University of Waterloo, Waterloo, Ont., 1981-82.

7.8 "Vacuum Pyrolysis of Lignocellulosics", University of Sherbrooke, Sherbrooke, Que., 1984-85.

7.9 "Catalytic Pyrolysis and Gasification of Ligno-Cellulosic Materials, University of Sherbrooke, Sherbrooke, Que., 1979-80.

7.10 "Catalytic Hydrogasification of Wood", University of Waterloo, Waterloo, Ont., 1984-85.

7.11 "Liquid Fuels and Chemicals from Lignocellulosic (Aspen) Materials", University of Saskatchewan, Saskatoon, Sask., 1979-84.

7.12 "Catalytic Upgrading of the Products of Wood Pyrolysis", NSERC study, University of Laval, Quebec, Que., 1983-84.

7.13 "Tall Oil as Fuel for Mobile Equipment in the Kraft Pulp Industry -- Phase I and Phase II", Prince Albert Pulp Company, Prince Albert, Sask., 1983-84.

7.14 "Development of Lignin Adhesives", Forintek Canada Corp., Ottawa, Ont., 1981-82.

7.15 "Characterization and Utilization of Lignin from Pretreated Lignocellulosic Substrates", Forintek Canada Corp., Ottawa, Ont., 1984-85.

# CHAPTER 8

# ENVIRONMENTAL CONSIDERATIONS

# CHAPTER 8

# ENVIRONMENTAL CONSIDERATIONS

## 8.1 INTRODUCTION

IT IS NATURAL to think of biomass as being a clean, environmentally benign energy source. Its potential for continued renewal contrasts sharply to the adverse effects of fossil fuel usage, including carbon dioxide build-up, acid rain and industrial smog. However, as demonstrated in many heavily populated, nonindustrialized nations, the large-scale use of biomass for basic energy needs may produce ecological upsets. Severe deforestation can lead to soil erosion and loss of arable land, siltation of rivers, flash floods, lowered water tables, and droughts.

In Canada, a relatively small population, vast biomass resources, and significant fossil fuel reserves have allowed problems of this magnitude to be avoided. Here, the use of biomass for energy has focused on the combustion of municipal and forest industry waste streams. In these cases, the energy derived provides an economic incentive for the environmentally acceptable disposal of what is otherwise waste material.

Federal initiatives in bioenergy have addressed a number of environmental concerns with respect to the future large-scale use of bioenergy in Canada. Studies on the increased removal of organic material from both agricultural and forest growth sites have provided valuable information on the recycling of biomass material to the soil. Research has shown that proper conservation practices can help prevent nutrient depletion and loss of soil organic content, thus promoting biomass growth potential and the preservation of wildlife habitats.

Other studies have examined the potential for air and water pollution associated with the harvest, transport, handling and storage of large quantities of biofuels. The thermochemical and biological conversion of raw biomass to prepared fuels, for instance, creates significant quantities of byproduct effluents that can pose health and environment hazards if not adequately treated.

## 8.2 ORGANIC MATERIAL REMOVAL

In Canada, most bioenergy is generated from processing residues that arise as part of normal agricultural and forest harvesting operations. However, a significant increase in biomass use for energy would require greater removal of material from the growth site. This increased harvest could have a serious impact on site ecology, affecting soil productivity, microbiological communities and wildlife. Positive impacts, such as reduced organic build-up in deep humic soils and improved wildlife habitats in overmature stands, would be minimal compared to the destruction of poor quality soils.

### 8.2.1 Agriculture

Intensive modern agriculture depends on the regular, large-scale supply of soil nutrients through artificial fertilizers. While increased harvesting of biomass for energy poses a negligible short-term effect on nutrient availability, potential long-term effects include soil loss and reduced organic content through water and wind erosion.

Loss of organic content leads to less effective utilization of chemical fertilizers as soil buffering capacity is lost. The loss of this tempering agent also results in higher soil temperatures, reduced water holding capacity and decreased soil aeration, leading to greater soil compaction and increased susceptibility to drought stress.

Considerable federal research effort has been devoted to determining the required levels of soil organics and it appears that safe crop residue removals can be specified for given soil types, crop systems and climatic conditions [project ref. 8.1].

### 8.2.2 Forestry

Since fertilization is not traditionally practised in Canadian forestry, increased biomass harvesting reduces nutrient recycling and can lead to a significant decline in site productivity. Compared to conventional bole-only harvest, whole tree harvesting increases the removal of biomass by about 50 percent and increases the loss of nutrients by 100 to 200 percent due to the removal of nutrient-rich foliage, twigs and small branches.

Le Groupe Dryade / UBC

Federally sponsored studies by Le Groupe Dryade Ltd. of Quebec, Que., and the University of British Columbia have shown that increased biomass removal can accelerate site degradation through erosion and soluble nutrient leaching

[project refs. 8.2, 8.3]. This is particularly critical in the harvest of low-quality stands growing on inherently poor sites. Since most forest soils are nutrient limited to some degree, especially with respect to assimilable nitrogen, short rotation plantations and whole tree harvesting can result in relatively rapid nutrient impoverishment. Medium- to long-term rotations result in moderate nutrient removal and are of less ecological significance. Federal research projects carried out at Dalhousie University and the University of Guelph have identified potential deficiencies of calcium, magnesium, phosphorous, sulphur and nitrogen. The specific effects of these deficiencies are dependent on tree species, age, site and region [project refs. 8.4, 8.5, 8.6].

Dalhousie / U. of Guelph

Wildlife is affected by increased biomass harvesting and shorter rotations in that the proportional representation of species is altered [project refs. 8.7, 8.8]. The habitat of certain species is improved, while for others the change is detrimental. For example, overall bird populations tend to increase, while cavity-nesting species such as woodpeckers tend to decrease in number. Similarly, younger stands increase the forage for deer populations, but are not suitable for species such as wood caribou, martin and owls.

Le Groupe Dryade

D.A. Westworth & Associates

## 8.3 BIOMASS STORAGE AND HANDLING

Biomass, which has a high moisture content to begin with, is often stored in outdoor piles exposed to rain. This can present a number of environmental problems. For example, most biomass fuels contain appreciable quantities of water soluble components that may leach out. The acidic nature of the leachate may create corrosion problems as well as contaminate surface or ground water.

Also, given adequate levels of moisture and atmospheric oxygen, microbial deterioration and auto-oxidation of the stored biomass can rapidly develop. These conditions can present the following hazards:

* The prolific release of pathogenic and allergenic spores pose a human health hazard.

* Oxidative processes can lead to severe oxygen deficiency in enclosed areas, thus posing a health hazard to anyone entering nonventilated bins or silos.

* Microbial activity and oxidative chemical processes produce a significant heat build-up which can, in extreme cases, lead to spontaneous ignition and fires.

Dry biomass fuels do not pose these problems, but may present others, such as dust. This may create a simple aesthetic nuisance, but concentrations of dust can produce fire or even

explosion hazards. Also, dust from certain types of biomass, such as Western Red Cedar, may be a severe allergenic threat. Other problems, associated particularly with municipal solid waste and animal waste, include odour, flies and vermin.

The technology required to ensure adequate environmental protection is available. The problem is ensuring its implementation. More work needs to be done on the causes and prevention of spontaneous combustion in storage and on the release and effects of fungal spores.

## 8.4 COMBUSTION

The combustion of biofuels is generally regarded as environmentally benign due to the low sulphur content of most biomass forms. The major emissions problem associated with biofuel combustion is the relatively high level of particulate matter in flue gases.

These particulates, composed of fuel ash, inorganic contaminants and unburned char, are controlled in large installations through special filter systems including multi-clones, electrostatic precipitators, wet scrubbers and baghouses. In medium- and small-scale units, cost considerations limit emission control equipment to multi-clones, while in household stoves and furnaces particulate control devices are rarely included.

Products of incomplete combustion, known as polycyclic organic materials (POMs) or polynuclear aromatic hydrocarbons (PAHs), have been found in association with unburned char particulate and have been identified as carcinogenic. Emissions of these hydrocarbons are not significant in well run, high-temperature industrial systems, but are prominent in emissions from air-tight stoves.

Research & Productivity Council

Under the Bioenergy Development Program, the Research and Productivity Council of Fredericton, N.B., measured emissions from several biomass-fired industrial combustion systems including a wood chip burner, a peat/oil burner and a hog fuel boiler [project refs. 8.9, 8.10]. PAH emissions were similar to those produced by the combustion of fossil fuels.

The major factor influencing the quantity and quality of emitted hydrocarbons was the design and operation of the combustion chamber. The lowest PAH levels were found in the hog fuel boiler, while high molecular weight PAHs were found more frequently in the chip burner. In all cases, low excess air was associated with enhanced PAH levels. The study concluded that efficient, controlled combustion plus standard emission control practices should be effective in preventing appreciable environmental emissions.

Envirocon / SNC Group

In another federal study, Envirocon Eastern Ltd. of Mississauga, Ontario, and the SNC Group of Montreal, Quebec, conducted a large-scale boiler test program on four pulp mill hog fuel boilers, including detailed emissions testing and analysis [project ref. 8.11]. This project is covered in more detail in Chapter 4, Direct Combustion.

The combustion of chlorine-containing MSW materials results in the air-borne emission of a highly toxic group of compounds -- dioxins and furans. These materials (also associated with the production and use of polychlorinated herbicides) are normally destroyed by high temperatures in a well operated combustor, but can escape under adverse combustion conditions.

### 8.4.1 National Incinerator Testing and Evaluation Program

In light of the potential for toxic emissions from the direct combustion of biomass, particularly MSW, the Canadian government has established the National Incinerator Testing and Evaluation Program (NITEP). Three generic types of energy-from-waste combustion facilities (mass burning, package incineration, refuse-derived fuel burning) are being extensively studied. The tests will relate measured emissions, including PCBs, dioxin, furan, PAHs, heavy metals and other toxic materials, to operating conditions. The results will be used to develop design and operating standards to minimize conventional and toxic emissions.

## 8.5 THERMOCHEMICAL CONVERSION

The thermochemical breakdown of biomass generally results in the production of three major products: noncondensible gases, condensible hydrocarbons and aqueous liquids, and char. The proportion of each depends on the specific process (gasification, pyrolysis, or liquefaction) and is closely related to temperature and rate of heating.

### 8.5.1 Noncondensible Gases

The noncondensible gases contain nonhazardous components such as carbon dioxide and oxygen, but may also contain poisonous gases such as carbon monoxide. They may also contain highly flammable explosive gases, such as hydrogen methane, and higher hydrocarbon gases, such as ethylene and propane. With adequate precautions, these gaseous components do not ordinarily pose an environmental or health hazard as they can be effectively destroyed by simple combustion.

### 8.5.2 Condensible Fractions

The condensible component resulting from the thermochemical breakdown of biomass includes tars, oils and aqueous fractions. It may contain over 200 compounds including acids, esters, alcohols, aldehydes and acetyls, ketones, phenols, furans, hydrocarbons, pyridines and carbohydrate derivatives.

A great number of the condensible tar/oil fractions have been tested as positive with respect to mutagenic activity. Condensible hydrocarbon components also pose a significant health hazard and, in particular, a severe water pollution hazard since they are often contained in the scrubber water used to cool and clean the gases used in energy generating equipment.

Tar/oil wastes can be disposed of by incineration or can be recycled. Aqueous effluents can generally be minimized by recycling or by neutralization and oxidation.

B.C. Research

In one federal study, B.C. Research collected samples of gasifier effluent from several different units for analysis and characterization [project ref. 8.12]. Ames tests were conducted and showed all samples to be mutagenic. Attempts at detailed chemical characterization, however, were not successful. Standard fractionation procedures yielded only complex mixtures of compounds, rather than individual compounds.

BBC Engineering

Many gasifier designs attempt to minimize the production of condensible organics through thermal cracking in a high-temperature bed of incandescent char. In a federally supported project, BBC Engineering of Markham, Ontario, examined the potential for reforming condensible organics to noncondensible gases in a catalytic cracker located outside the gasifier [project ref. 8.13]. When operated above 450°C, a fluidized-bed reactor using a low-cost limestone catalyst successfully minimized pollution without affecting the heating value of the gas product. Tar cracking investigations are being continued in association with BIOSYN's syngas project (see Chapter 5, Conversion to Liquid Fuels).

Several U.S. gasifier manufacturers are currently considering the use of catalytic cracking to reform condensible organics.

## 8.6 BIOLOGICAL CONVERSION

Environmental problems have not yet been encountered in biological conversion processes. The production of ethanol from corn is a well established process and waste streams such as spent yeast and waste media are either sold or

treated before discarding. Most, if not all, of the microorganisms used in bioconversion processes occur naturally in the environment, although some mutated species may differ slightly from the original parent strains. More attention will be given to the environmental impact of these processes as they approach commercially viability.

## 8.7 SUMMARY

In addition to air-borne emissions, the handling, transport and disposal of ash from biomass conversion systems can pose environmental hazards. Dry ash systems present dust problems, while wet systems promote corrosion. Leachates from ash disposal sites can have undesirable effects if allowed to enter water courses. Nevertheless, the implementation of known conversion principles and emission control procedures can limit the environmental impact of bioenergy processes to acceptable levels.

In medium and large industrial combustion projects, environmental standards are normally addressed, but in research projects and small-scale domestic applications principles of good combustion are not always applied. This is most notably the case in domestic solid wood fired space heaters.

Ongoing federal efforts will focus on the detailed, intensive monitoring of commercial combustion systems, both to measure and characterize emissions and to relate this data to operating procedures and system design. As well, work is under way on improved control systems, particularly in the on-line measurement of biofuel properties. Finally, increased biofuel enhancement to produce a uniform fuel with specified properties and performance would greatly reduce environmental problems.

## 8.8 FEDERAL PROJECT REFERENCES


8.1 Colwell, H.T.M., "The Potential for a Sustained Energy Supply from Combustible Crop Residues in the Canadian Agriculture and Food System", Agriculture Canada, 1982-83.

8.2 "The Nature and Extent of the Impact of Forest Biomass Harvesting on the Forest Environment", Le Groupe Dryade Ltd., Quebec, Que., 1979-84.

8.3 "Modelling of the Long-Term Consequences of Intensive Harvesting on Soil Fertility and Biomass Production", University of British Columbia, Vancouver, B.C., 1979-84.

8.4 "Effects of Harvesting Biomass For Energy on Nutrient Status and Long-Term Productivity of Forest Sites", Dalhousie University, Halifax, N.S., 1979-83.

8.5 "Nutrient Content of Various Types and Parts of Plant Samples from the Forest at Petawawa National Forestry Institute", University of Guelph, Guelph, Ont., 1982-83.

8.6 "Impact of Harvesting Mature Trees by the Whole-Tree Method on the Microbiology, Organic Matter and Nitrogen Transformation of Forest Soil", University of Guelph, Guelph, Ont., 1981-84.

8.7 "Impact of Biomass Production on Wildlife", Le Groupe Dryade Ltd., Quebec, Que., 1980-83.

8.8 "Impact on Wildlife of Short-Rotation Management in Boreal/Aspen Stands", D.A. Westworth and Associates, Edmonton, Alta., 1981-83.

8.9 "Identification of Hydrocarbon Emissions from Industrial Combustion", Research and Productivity Council, Fredericton, N.B., 1980-82.

8.10 "Emissions Testing of Four Particulate-Fired Appliances in the Fredericton Area", Research and Productivity Council, Fredericton, N.B., 1981-84.

8.11 "Test Program on Boilers Burning Wood and Refuse", Envirocon Eastern Ltd., Mississauga, Ont., 1982-85.

8.12 "Characterization of Tar Produced During the Gasification of Wood", B.C. Research, Vancouver, B.C., 1980-81.

8.13 "Evaluation of Reforming as a Practical Technique for the Elimination of Water Pollution from Wood Gasifiers", 445872 Ontario Inc. (BBC Engineering), Markham, Ont., 1980-81.

INDEX BY PROJECT CONTRACTOR


ADI Ltd. ..... 67, 79
Avtech Electrosystems ..... 16
BBC Engineering ..... 100
B.C. Research ..... 22-26, 49-51, 89, 100
B.H. Levelton and Associates ..... 26, 28
BIODEV ..... 73
Biohol ..... 91
Biomass Combustion Ltd. ..... 25
Bioshell Inc. ..... 27
BIOSYN ..... 53, 73, 75
Canviro Consultants ..... 79
Carleton University ..... 16
CBCL Ltd. ..... 11
Centre de Recherche Industrielle du Quebec ..... 23
Dalhousie University ..... 97
D.A. Westworth and Associates ..... 97
Domtar Inc. ..... 35
Econotech Services Ltd. ..... 55
Eco-Research ..... 72, 75
Envirocon Eastern Ltd. ..... 99
Forest Engineering Research Institute of Canada ..... 21, 23
Forintek ..... 14-16, 25, 53-57, 69, 91
Inco Metals ..... 74
Inproheat Industries ..... 21
Iotech ..... 55, 56, 91
General Communution Inc. ..... 21
H.A. Simons Ltd. ..... 36
Heuristic Engineering ..... 71
K.C. Jones and Associates ..... 23
K.C. Shen Technology International Ltd. ..... 28
Labatts ..... 57
Lamb-Cargate Industries Ltd. ..... 35
Le Groupe Dryade ..... 96, 97
Logging Development Corp. ..... 24
Loucks Oceanology ..... 11
McGill University ..... 50
Mohawk Oil ..... 58, 91
Omnifuel Gasification Systems ..... 72, 75
Ontario Research Foundation ..... 28, 73
P.E.I. Energy Corp. ..... 69
Prince Albert Pulp Company ..... 91
Pulp and Paper Research Institute of Canada ..... 16, 18, 35, 77
Pyrosol ..... 47
Queen's University ..... 69
Regatech ..... 74
Research and Productivity Council ..... 98
Resorption Canada ..... 77
Rockwell International ..... 76
Sandwell and Company Ltd. ..... 18, 39
Saskatchewan Power Corp. ..... 69
SNC Group ..... 76, 99

INDEX BY PROJECT CONTRACTOR (continued)

St. Lawrence Reactors ..... 54
Stake Technology ..... 18, 55
Techwest Enterprises ..... 69
Tigney ..... 55
University of British Columbia ..... 55, 96
University of Guelph ..... 97
University of Laval ..... 89, 90
University of Quebec ..... 50
University of Saskatchewan ..... 50, 90
University of Sherbrooke ..... 47, 51, 90
University of Toronto ..... 21, 50, 55, 78
University of Waterloo ..... 48, 55, 78, 90
University of Western Ontario ..... 49, 51, 77, 89
W & Y Consultants ..... 16
Wastewater Technology Centre ..... 47, 79
Westwood Polygas ..... 67
W.L. Wardrop and Associates ..... 53